POSSUM RESOURCE SELECTION IN A FRAGMENTED LANDSCAPE, CASS, NEW ZEALAND.

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Eykolina Jacoba de Zwart

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FORESTRY THESIS

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Abstract

This study presents the results of an investigation to determine the resources utilised by possums in a spatially heterogeneous landscape in the Canterbury high country. The study area comprised a mosaic of forest, scrub, shrubland, grassland and swamp at the University of Canterbury field station at Cass, inland Canterbury.

The vegetation communities at Cass were originally divided into seven different categories based on species composition. These areas are referred to as the swamp, grassland, shrubland, scrub1, scrub 2, native forest, and exotic forest. Communities were classified using two multivariate techniques; TWINSPAN and Detrended correspondence analysis. A vegetation map of Cass was produced using ground survey and aerial maps, and displayed the extent and coverage of vegetation communities. These vegetation communities reflect the influence of burning and farming. The study area comprises c. 195 ha.

The overall possum density was low, with approximately one possum per hectare. This result may be due to resources that possums need for survival, being deficient in the area.

Possum movements were investigated by radio-collaring six female possums and six male possums at Cass. These possums were radio-tracked six times during a period of ten months, with each radio-tracking session undertaken for a period of three consecutive nights. The data collected were used to derive individual home ranges using Minimum Convex Polygon and Kernel home range estimates. There was no statistically significant difference between female and male home ranges at Cass. No seasonal difference in possum home range was detected, although other possum home range studies have found seasonal differences. There were too few den site location areas to enable accurate information concerning seasonal variation of den sites. Possums had relatively large home ranges, which probably result from a low possum density in the areas, as well as spatial heterogeneity of key resources. Nine possums showed some degree of home range overlap, but there did not appear to be any difference between females and males with respect to this. Sixty percent of the possums studied exhibited bimodal home ranging behaviour. Bimodal behaviour almost certainly results from the spatial heterogeneity of key resources, with possums having to travel long distances in order to use all the resources.

Possum diet was assessed using a point sampling technique, which identifyied all ingested stomach material greater than 3mm, at four times through 2001. There was no statistical difference between female and male diet, or between juvenile and adult diet. Thirty-eight different food items were consumed by possums over the study period, with four dominant food items that comprised of 50% of their diet (*Aristotelia fruticosa*, fungi, *Podocarpus nivalis*, and *Blechnum penna-marina).*

Due to the spatial heterogeneity of vegetation communities at the Cass study area, possums utilised the different habitats non-randomly, preferring the scrub and forest communities.

Possum management is not currently needed at Cass, although in the future, if possum density increases than management options should be reassessed in order to minimise possum impact.

Chapter 1 Introduction

Introduced herbivores are considered the single biggest threat to New Zealand's indigenous biodiversity (Cowan *et al.*, 1985). These herbivores have the ability to alter vegetation composition, structure and dynamics, which may result in local and possibly national extinction of New Zealand's indigenous species. To study an introduced animal, it is important to understand how they have survived in a completely new environment, such as their movement, diet, and how they select these resources. This knowledge will enable effective management of these herbivores in the future.

In 1858, the brushtail possum (*Trichosurus vulpecula* Kerr) were first officially recorded at having been successfully introduced into New Zealand from Australia, although earlier releases may have taken place (Pracy, 1974). Possum's were primarily introduced into New Zealand to establish a fur trade (Davidson, 1969). Now, 90 percent of New Zealand's land area has been colonised by possums since those first introductions (Livingstone, 1993). The possum-free areas are generally offshore islands (such as Rangitoto, Motutapu, Kapiti, and Great Barrier), as well as parts of Fiordland. Possums occur across a wide range of vegetation types, including orchards, urban areas, native and exotic forests, and are distributed from sea level to the alpine zone.

A good understanding of possum biology has important implications in possum management in terms of how quickly the population will increase, and how quickly possums disperse into other areas. Adult females are polygamous and polyoestrous, with the oestrous cycle lasting up to 26 days, which is approximately eight days longer than pregnancy (Fletcher and Selwood, 2000). Twins are rare, but different sized young have been found in one pouch (twins are more common in Australian possums). This could result from cross-fostering of older offspring when several females den together. Alternatively the failure of lactation inhibits oestrus, which leads to a second birth approximately 30 days later (Cowan, 1990a). The main birthing season in possums is autumn to spring (March to November) (Cowan, 1990a; Brockie, 1992; Fletcher and Selwood, 2000). Generally, heavier females breed earlier (Fletcher and Selwood, 2000). This has also been found in possum populations in Tasmania and New South Wales, Australia (Humphreys *et al.*, 1984). Humphreys, *et al.*, (1984) concluded that food resources are prime regulators of breeding in Australia.

It has been found that females in exotic forest or pasture/scrub breed in spring more often than females do in native forest (Fletcher and Selwood, 2000). Spring breeding is related to habitat and population density, both of which affect female condition. Females may breed in autumn and spring, but only if they breed in early autumn and their body condition is above average.

Male possums generally mature at one or two years, which is slightly older than females (Fletcher and Selwood, 2000). At puberty, the possum's testes grow rapidly to adult size. Throughout an adult male possum's life, the weight of the testes does not vary with seasons. However, the epididymis is about 25% heavier in the breeding season. The weight of the prostate gland increases fourfold between mid February and late March (before breeding). This is in response to changes in the testosterone levels, which are probably stimulated by pheromones from the oestrous females. Seasonal peaks of conception are associated with changes in prostate and epididymis size (Fletcher and Selwood, 2000).

Newborn possums (joeys) are born weighing approximately 0.2 grams after about 17 days gestation (Fletcher and Selwood, 2000). The offspring have well-developed forelimbs, mouth, lungs, upper digestive tract, and olfactory epithelium, but the hindlimbs are rudimentary. Immediately after birth the joey climbs unaided from the urogenital opening to the pouch. It is believed that the olfaction guide the joey (Fletcher and Selwood, 2000). The joey attaches its' mouth to its' mothers teat, which swells up within the new-borns mouth and remains there permanently attached for approximately 70 days, after which the joey will voluntarily release itself from the teat. From approximately 120 to 140 days the offspring gradually become independent but are still found in their mother's home range. Weaning is generally completed by 240 days after birth (Fletcher and Selwood, 2000). Males have no part in rearing their offspring (Fletcher and Selwood, 2000).

An understanding of the possum reproductive habits will enable researches to make inferences on how they respond to their environment. If their environment has many available den sites and high quantities of nutritious food resources, then it would be expected that there is a high population density, as well as a high proportion of offspring born in the area. Therefore it is important to estimate how a possum population responds to their environment, which can be done by studying possum resource selection in an area. By researching possum resource selection (such as possum diet and movements), inferences

can be made on how the possums may be affecting the area in terms of environmental issues.

Possums occupy a number of habitats ranging from indigenous and exotic forests, to scrublands and pasturelands (Jolly, 1976). Possums have readily adapted to New Zealand's unknown environment and alien diet (Fitzgerald, 1984; MacLennan, 1984) and have prospered to the extent that they are now considered a national pest. Possums have been known to defoliate canopies and increase tree mortality resulting in wide spread forest dieback and changes in forest canopy compositions, and compete with native fauna for resources.

Possums are primarily herbivorous and have adapted to foraging a wide range of plants in New Zealand, although possums do feed on some plant species more than others (Kean, 1959; Fitzgerald, 1976; Campbell, 1990). Individual plants can be defoliated and killed by prolonged possum browse (Meads, 1976; Batcheler, 1983; Payton, 1988). Originally it was thought that foliage was the primary food source for all their dietary needs. Now the focus has been shifted to other food sources. Even though foliage is the main food source, it is thought that possums need foods that are high in energy and/or nutrients (such as fruits, flowers, and invertebrates) in order to maintain their high population densities in most New Zealand habitats (Nugent *et al.*, 2000). The use of these high energy and nutrients may be resulting in competition with native fauna.

Competition with native fauna over natural resources is a conservation issue in New Zealand. Competition for food resources may occur between possums and native birds as studies have found that these animals share many kinds of flowers, leaves, fruits, and insects (Brockie, 1992). It was found on Kapiti Island that for most of the plant species that possums browsed that the removal of possums resulted in plant numbers increasing and more plants flowering (Payton, 2000). There has also been an increase in bird numbers now that possums are absent.

Invertebrates that are found in the possum diet are characteristically large, slow-moving species such as beetles, cicadas, stick insects, weta, and fly larvae (Cowan and Moeed, 1987). While most possum diet studies found that invertebrates were absent or only made up a small component of the diet (Gilmore, 1967; Fitzgerald, 1976; Clout, 1977;

Warburton, 1978; Coleman *et al.*, 1985; Rickard, 1996), some studies have observed significant numbers of invertebrates in their diet, at least seasonally (Cowan and Moeed, 1987; Owen and Norton, 1995).

Possums have been known to predate on vertebrates (Brown *et al.*, 1993). Fantails (*Rhididura fuliginosa*), kāhu (*Circus approximans*), kererū/kūkupa (*Hemiphaga novaeseelandiae*), kiwi (*Apteryx* species), and kokako (*Callaeas cinerea*) have all been predated on by possums as eggs, nestlings, or adults (Brown *et al.*, 1993). James and Clout (1996) indicate that possums are increasingly becoming a contributing factor in the decline of these species, although vertebrates have seldom been reported in possum diet. If birds are in possum diet, usually a few feathers will indicate this. Possums have been observed eating dead deer (Thomas *et al.*, 1993) and have also been caught on meat-baited ferret traps (Caley, 1998). In most situations, possum impact on native vertebrates in terms of competition for resources, rather than predation.

Possums not only negatively affect indigenous biodiversity, but they are also a concern to the dairy, beef, and pastoral farms, horticulturists, and foresters alike. Possums are the known primary wildlife reservoir for bovine tuberculosis (Tb), which is a disease caused by *Mycobacterium bovis* with cattle (*Bovis* species) being its natural host (Coleman and Caley, 2000). Bovine tuberculosis, in cattle, is an incapacitating, and often fatal disease, which is easily transmitted to other cattle. Deer may also become infected with Tb.

Approximately 23.6% of New Zealand is occupied with Tb-infected possum populations (Anon, 2000b), with the main areas being the Central North Island, Wairarapa, North Canterbury, Westland, and Otago (Coleman and Caley, 2000). The spread of Tb in New Zealand continues, and the main cause is suspected to be juvenile male possums (Cowan *et al.*, 1996).

Not only is there a problem of Tb to human and animal health, but also to New Zealand's national and international economic trade health. The office of International des Epizooties (OIE) sets international standards for Tb-infected animals within countries (Coleman and Livingstone, 2000). The OIE consider a country to be free of Tb when 99.8 % of all herds present in a country have officially been tested free of Tb. From 1997 to 1999, 97 percent of New Zealand's herds were classed as Tb-free. Due to New Zealand having less than the

obligatory Tb status, Tb is a significant problem (Coleman and Livingstone, 2000), especially since the New Zealand's dairy industry contributes approximately 20 percent (NZ$4.2 billion) of all foreign trade. The beef industry contributes NZ$1 billion, and the deer industry less that NZ$177 million (these figures are based on 1996/97 and 1997/98 figures, (Coleman and Livingstone, 2000)).

Pastoral, horticulture, and forestry are also negatively affected by possums. Possums forage on the pasture (Hackwell and Bertram, 1999 in Butcher, 2000), horticultural produce (Butcher, 2000), and young exotic trees (Butcher, 2000).

It is important to manage possums for the environmental, human, and economic health of New Zealand. To manage possums effectively it is important to understand which part of the environment the possums are negatively impacting on, and how this impact occurs. Possums in different environments will have different impacts, thus it is important to study possums in a range of different environments in order to create different management strategies that will work effectively in the different environments.

Traditionally land management in New Zealand has been separated into public conservation lands and values, and secondly, private lands (Norton, 2001). The focus now is to try and integrate these two land uses (Norton and Miller, 2000). This change in land management view will acknowledge that while landowners have legitimate rights to obtain an economic return from their land, they also need to sustain indigenous biodiversity values (Knight, 1999; Norton, 2000).

Private landowners should not have to compromise their economic rights to achieve nature conservation rights (Mulcock, 2001). Economic values on private land involve agricultural uses such as forestry and grazing (Norton, 2001). Tourism also is provides an income to private landowners, which includes recreational activities, such as jet boating, fishing, hunting, tramping, mountain biking, and rock climbing. Integrating economic values with indigenous biodiversity values will improve the tussock grassland habitats on private land (Mulcock, 2001).

The importance of sustaining biodiversity values on private land has been recognised in a number of recent government initiatives (Norton, 2001): Resource Management Act 1991,

Forests Amendment Act 1993, *New Zealand Biodiversity Strategy* (Anon, 2000c), Ministerial Advisory Committee, *Bio-What?* (Kneebone *et al.*, 2000), and *Biodiversity and Private Land* (Anon, 2000a). With the support of local, regional, and central government, conservation values will benefit as these support units help acknowledge the importance of nature conservation on private lands, share the responsibility with the communities, provide better resource management of public lands (Department of Conservation), and provide more resources for independent land conservation trusts, such as QE II National Trust, and the Landcare movement (Mulcock, 2001).

Pastoral leases and special leases include approximately 2.45 million hectares, which is approximately 10% of New Zealand's land area (Norton, 1991). Areas of the lowland and montane tussock grasslands similar to Cass make up approximately 1.6 million ha of New Zealand (Newsome, 1987). Now with the land tenure up for review more lowland and montane tussock lands are being brought into the national conservation estate (McGlone, 2001), therefore it is important to understand the role of possums in these ecosystems and especially in areas where possum may influence ecosystem processes such as succession. There have been no published possum studies that have looked at a native high country farmland, but there have been studies that have been based at lower altitudinal areas with a similar heterogeneous landscape (Gilmore, 1967; Jolly, 1976; O'Cain, 1997), although only (Jolly, 1976) has studied habitat selection. This study sought to evaluate all these issues. This study is situated at the Cass field station, University of Canterbury, and is leased to Craigieburn Station for high country sheep farming, and has spatially heterogeneous mosaic of regenerating vegetation.

The aims of this study are:

1) To describe the geology and landforms, soils, climate, fauna, and the history of Cass and the surrounding areas (including vegetation and human)
2) To describe the current vegetation pattern of the Cass study area thus enabling a quantitative assessment of the vegetation
3) To assess possum movements in the Cass study area
4) To assess possum diet in the Cass study area
5) To assess possum resource selection in the Cass study area
6) To recommend necessary management implications for the control of possums in the Cass study area.

Chapter 2 Site description

2.1 Introduction

The Cass Research Area (1776 ha), in which this research was undertaken, is located on the eastern side of the Southern Alps, Canterbury, New Zealand, 43°01' S, 171°47' E, altitudinal range 550-1360m, (Figure 2.1). This site is located within the Cass Ecological District, Puketeraki Ecological District. The research area is centred on Cass Hill (1098m) and Sugarloaf (1359m), and is bounded by the Waimakariri River to the north and east, and the Cass River, State Highway 73, the Craigieburn Road, and Lake Sarah to the west and south. It comprises the steep slopes of Cass Hill and Sugarloaf and the more gentle fans and terraces that surround them. The research area, which is on land owned by the University of Canterbury, is managed primarily for educational and research purposes, but is subject to light sheep grazing under a lease agreement with Craigieburn Station.

Within the research area, a smaller study area was the focus of the research described in this thesis (Figure 2.2). This area includes the lower southwest slopes of Cass Hill and Sugarloaf and part of the fan system formed by the streams that drain Reservoir Bush, Middle Bush, Sugarloaf Bush, and Chilton Valley. The study area also comprised part of the swamp along Grassmere Stream and the river flats on which the Cass settlement is located. The study area ranged in altitude from 550-900m and consisted of an area of c. 195 ha.

The aim of this chapter is to describe the geology and landforms, soils, climate, fauna, and the history of Cass and surrounding areas and present vegetation, and to explain the major ecological patterns and the environmental factors influencing these patterns at Cass and in the surrounding area. Background knowledge of the study site will help in making inferences as to why present vegetation communities exist, which in turn influence possum resource selection behaviour.

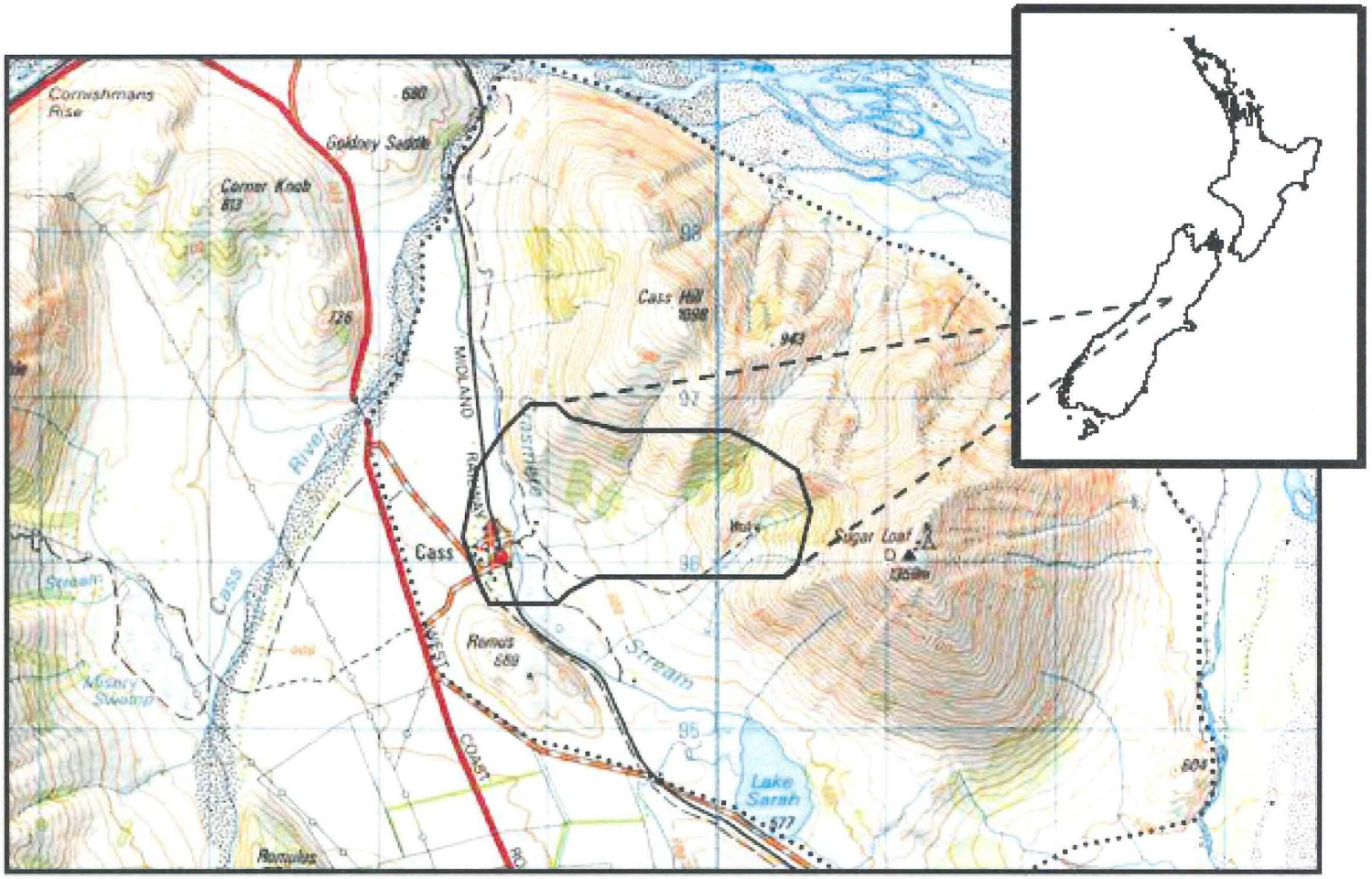

Figure 2.1 Cass Research Area, showing c. Cass Research Study Area (-), c. Cass Research Area (….), Canterbury high country, New Zealand (Map K34-L34 taken from Dept. of Survey and Land Information).

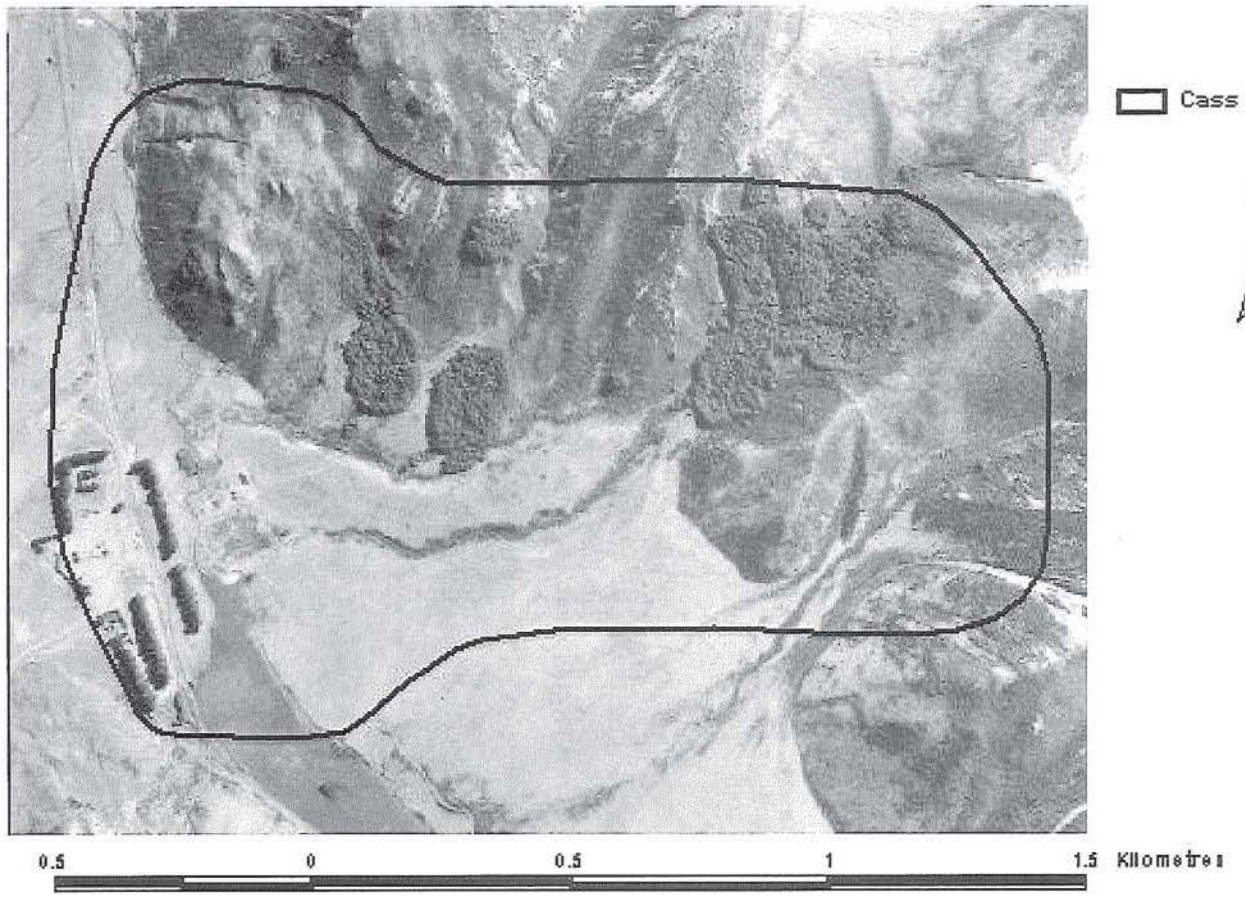

Figure 2.2 Aerial photo of Cass study area, Canterbury high country, New Zealand.

2.2 Geology and landforms

The underlying rocks comprise moderately indurated sandstones and mudstones (Greywacke) that have been uplifted over the last 65 million years (late Cenozoic period that marks the construction of the basins and a progressive uplift of New Zealand into a mountainous land) (Bradshaw, 1977). However, current landforms are very much the product of recurrent glacial activity during the last 2-3 million years. Major glaciers originating along the main divide of the Southern Alps have flowed eastwards towards the coast and in the past have overridden Cass Hill and Sugarloaf, resulting in their rounded tops. The last glacial advance (the Otiran Glaciation) resulted in a major valley glacier moving down the Waimakariri Valley to the north and east of Cass Hill and Sugarloaf, with a terminus 10 km southeast of the Cass Research Area. A smaller lobe of this glacier ran around the south-western side of the research area with a terminus formed where Lake Sarah is now located. Since glacial retreat commenced c. 14,000 years ago, active erosion has continued to round the hill sides and in particular to form the fans around the base of Cass Hill and Sugarloaf, including much of the study area (Gage, 1977).

Historical faulting, differential uplift, and glaciation formed the geological structure of the Cass District (Soons, 1977). In most areas, erosion and deposition from tectonic movements continues today, although the frequency and intensity with which they occur vary (Soons, 1977). Mountain areas generally resulted from tectonic movements (Soons, 1977). The land surface in the Cass District has been successively developed during the last three climatic oscillations of the Late Pleistocene time (Porika Glaciation, Waimaunga Glaciation, and Otira Glaciation) (Gage, 1977).

2.3 Soils

Soils at Cass comprise mainly yellow-brown earths on the slopes and recent soils on the flats with the former more widespread (Cutler, 1977). The yellow-brown earths are strongly leached and occur on high fans, terraces and moraines, which are where soil formation has proceeded for long periods. The soil structure is usually moderately developed, composite and crumbly (granular and often very fine) (Cutler, 1977). The colour and structure of the soils is often a reflection of the abundant hydrous oxides of aluminium and iron in the soil. Before Polynesian fires, most soils in the Cass area probably carried forest for a significant part of the soil-formation period (Cutler, 1977).

2.4 Climate

The Southern Alps largely determine the climate experienced at Cass. Mountains experience large variations in temperature caused by differing altitudes. Higher altitudes usually experience higher wind speeds and solar radiation (if cloud cover is absent) than lower altitudes. Airflow is cooled quickly on the windward side, resulting in condensation and orographic precipitation. North-west winds are formed when dry air travelling down the lee side of the mountains is warmed.

2.4.1 Cass macro-climate

The annual average air temperature experienced at Cass (1998-2001) is 9.8°C, with an average temperature in February of 16.4°C and the average temperature in July of 3.1°C (Table 2.1). This temperature range is similar to that recorded during the early 1960s (1961-1964), when the annual average temperature was 9.0°C, with the average temperature in February around 15.7°C, and average temperature of 1.6°C in July (Table 2.1). During 1998-2001, the coldest months average daily minimum temperatures occurred in June (0.4°C), July (-1.2°C), and August (-0.2°C) (Table 2.2). The warmest average daily maximum temperatures over this period occurred in January (20.0°C), February (22.5°C), and March (20.0°C) (Table 2.2). These high maximum temperatures are caused by the large amount of solar energy absorbed by the soil and made available to warm the air in summer (Greenland, 1977). Previous records at Chilton Valley show an absolute maximum temperature of 40°C and an absolute minimum low temperature of -8.5°C, while previous records at the Cass Field Station showed an absolute maximum record of 37°C and an absolute minimum of -16°C (Greenland, 1977). The extreme temperatures generally occur when there is little moisture in the soil in summer to utilise some of the solar energy in the evaporation process. Extreme summer temperatures are caused by the north-westerly airflows. The winter temperatures are not as low as would be expected at this altitude and latitude (Greenland, 1977). One reason for this is the large amount of heat gained by the air as it passes over the Tasman Sea.

Solar radiation maximum and minimum recordings are similar to the maximum and minimum temperatures that were recorded at Cass. December had the highest solar flux recordings in both periods (Table 2.1). January and February are the next two highest solar flux records at Cass. June had the lowest solar fluxes in both periods, with July and May

having the next lower solar fluxes. As can be seen in Table 2.1, solar flux recordings have increased over the past 40 years. This may be due to the effects of global warming, but the most likely reason is the different measuring equipment used in the different periods.

Average rainfall has not changed dramatically over the past 40 years (Table 2.1), although on a monthly basis, it appears that average rainfall from 1998-2001 is more irregular than average rainfall in 1961-1964. This may be caused by El Nino and la Nina climatic patterns, and possible influences of global warming. Although, the short intervals of the time periods used may possibly be limiting the accuracy of the data.

Snow is not common at the Cass Research Area. Snow will generally only be present for a few days on a few occasions in winter (Greenland, 1977). Occasionally if heavy snowfalls occur, the snow may persist for weeks, but this is uncommon. Hoar frosts do occur frequently at Cass over winter (personal observation). These hoar frosts generally occur on the south-facing slopes of Sugarloaf and Cass Hill, and they may exist for long periods as these areas receive little or no sunlight for long periods. This has also been associated with persistent valley floor fogs that are a regular occurrence in the area in winter (D. Norton, pers. comm.).

Table 2.1 Comparison of mean air temperatures (degrees Celsius), solar radiation, and mean rainfall (mm) at Cass Field Station (data provided by (Greenland, 1977), Plant and Microbial Sciences Department, University of Canterbury).

Altitude 566 (m) Years of Record	1961-1964			1998-2001		
Month	Air Temp. (°C)	Solar flux (W/m^2)	Rainfall (mm)	Air Temp. (°C)	Solar flux (W/m^2)	Rainfall (mm)
January	14.6	444	111	14.6	585	82
February	15.7	439	89	16.4	508	49
March	13.2	318	96	13.9	401	53
April	8.8	188	104	10.3	267	117
May	5.8	109	124	7.9	168	82
June	2.7	51	103	4.2	124	127
July	1.6	83	102	3.1	158	110
August	3.7	155	105	4.4	226	110
September	5.7	263	110	7.8	335	92
October	9.8	358	130	10.4	402	232
November	11.5	392	115	10.9	505	89
December	15.5	508	111	14.0	588	96
Year	9.0	276	1300	9.8	356	1238

Table 2.2 Average minimum and maximum temperatures at Cass Field Station during 1998-2001 (Plant and Microbial Sciences Department, University of Canterbury).

Month	Minimum air temperature	Maximum air temperature
January	9.5	20.1
February	10.6	22.5
March	8.7	20.0
April	5.5	15.8
May	3.6	12.7
June	0.4	9.0
July	-1.2	8.8
August	-0.2	9.9
September	3.0	13.2
October	6.0	15.4
November	6.0	16.0
December	9.1	19.2
Year	5.1	15.2

2.4.2 Cass micro-climates

Micro-climatic effects are present at Cass, although the climate data recorded from Chilton Valley indicated no major differences between here and the field station (Greenland, 1977). Micro-climatic differences are due to the topography and surface cover of the surrounding landscape. The terraces, gullies, and hillfaces all affect the climate throughout Cass Basin. The effects of humidity, temperature, and wind all affect the temperatures within the different physiographical features (gullies provide shelter from wind, as well as acting as a heat sink, thus humidity in gullies will be higher than on terraces and hillfaces) (Greenland, 1977). These different microclimates influence the vegetation pattern that occurs at Cass. One example at Cass is the vegetation contrast between the eastern and western sides of Chilton Valley (Greenland, 1977). The eastern side is predominantly *Leptospermum scoparium* and the western side tussock, *Hebe* species, *Dracophyllum* species, and forbs. Many of the gullies present on the terraces at Cass are predominantly scrub species, whereas the surrounding terraces are predominantly grass species. This may also be related to the disturbance history at Cass.

2.5 Fauna

Sheep have been farmed in the Cass area primarily for wool and meat from 1877 onwards (McLeod and McLeod, 1977). Possums (*Trichosurus vulpecula*), hedgehogs (*Erinaceus europeaeus*), mice (*Mus musculus*), feral pigs (*Sus scrofa*), stoats (*Mustela erminea*), and red deer (*Cervus elaphus*) are also present at Cass in varying numbers (Johns, 1977). Avian

fauna that is present at Cass include morepork (*Ninox novaeseelandiae*), bellbird (*Anthornis melanura*), grey warbler (*Gerygone igata*), tomtit, and fantail (*Rhipidura fuliginosa*). For a more detailed description of the fauna that is present in the Cass area, see Johns (1977).

2.6 Human and vegetation history

2.6.1 Pre-Human

Periodic fires and sedimentation occurred on the Canterbury Plains approximately 1500 to 6500 years ago (Molloy, 1977). These fires were natural occurrences as humans were not present in New Zealand at this time. Evidence from Lake Lyndon and Mt. Misery indicate that *Pyllocladus* shrubland was widely developed over the landscape until approximately 7000 years ago. Since then natural fires, along with climatic changes, may have reduced these shrublands and aided the expansion of *Nothofagus* forest (Molloy, 1977). Forestation occurred approximately 10 000 years (McGlone, 1988).

2.6.2 Polynesian settlement

Radiocarbon dating indicates widespread forest destruction by fires between 500 and 1000 years ago (Molloy, 1977). The general belief is that early Polynesian hunters deliberately or accidentally lit these fires. Polynesian fires probably burnt mountainsides and some alpine vegetation in the Craigieburn Range (Molloy, 1977). Traces of burnt plant remains were found buried in soils up to altitudes of 1500m. It is thought that barren alpine and sub-alpine areas originated during this period resulting in loss of soils under the momentum of the extremely erosive forces that operate on bare ground at higher altitudes (Burrows 1977). Table 2.3 shows all known Polynesian fires at Cass and nearby areas.

Polynesian fires generally cleared forests and reduced snow-tussock grassland above the tree limit. Typically, short-tussock grassland and regenerating shrubland replaced forests following fire. Other features that reflect Polynesian fires at Cass involve the decline of the forest area, prevalent hybridisation in the flora and hastened erosion (Molloy, 1977). Hybridisation is a widely recognised feature of New Zealand flora (Lloyd, 1977), and is prevalent in areas like Cass because species previously separated by forest have expanded their range after deforestation and now come into regular contact (e.g. *Dracophyllum* species and *Podocarpus* species).

Table 2.3 Radiocarbon dates for charcoal derived fires at Cass and around nearby places (Molloy, 1977).

Locality	Altitude	Species	Age years before 2002
Porters Pass	1067	Mountain beech	1002±105
Woolshed Hill	730	Mountain beech	838±53
Porters Pass	975	Mountain beech	752±105
Lake Lyndon	854	Mountain beech	664±70
Broken River	945	-	661±95
The Pyramid	970	Red beech	616±50
Porters Pass	1067	Mountain beech	562±50
Woolshed Hill	701	Red beech	559±53
Lake Lyndon	854	Mountain beech	558±70
Trig H.	823	Red beech	540±52
Woolshed Hill	620	Red beech	533±40
Craigieburn	1006	-	517±33
Lake Lyndon	854	Mountain beech	498±70
Woolshed Hill	1113	Mountain beech	442±37

2.6.3 European settlement

From 1850 onwards, European settlers set out to create extensive grazing runs in areas that were easily accessible such as tussock grasslands in the Waimakariri Basin (McLeod and Burrows, 1977). The extensive grazing runs were stocked with sheep. By 1855, almost all of the lower country was in use, forcing European settlers to search for land in more remote valleys. During this period of colonisation in and around the Puketeraki Ecological Region, burning of large areas of vegetation was visible from Christchurch (McLeod and Burrows, 1977).

The first recorded burning was in 1857, with extensive burnings continuing until the 1960s (Molloy, 1977). Major burning in the Cass area consisted of forest clearance in the lower Cass River Valley (Table 2.4) and the northern flanks of the Craigieburn, Black and Academia Ranges-Mt. Misery (McLeod and Burrows, 1977). European fires (1860s to 1890s) were used to remove forest and create grassland for pastoral farming, which has resulted in severe soil erosion in some areas. Continued burning kept grassland areas free of regenerating shrubland (up to 1920s). Between 1920 to 1960, fires were generally accidental, keeping these areas as degraded shrubland and grassland. Areas that were not burnt and had low stock numbers slowly converted first to mixed scrublands then to beech forest.

Table 2.4 Fires in the Cass District since European settlement (Molloy, 1977).

Year	Location	Vegetation type
~1914	Chilton Valley	Scrub, grassland
1914	Near Cass Field Station	Grassland
1919	Near Cass Field Station	Scrub, grassland
1920	Sugarloaf	Scrub, grassland
~1935	East and of Sugarloaf	Scrub, grassland
1947	Fan near Cass Field Station, lower slopes Cass Hill, Sugarloaf Fan	Scrub, grassland
1995	Close to Cass Field Station (~ 0.5 ha) towards Sugarloaf Hill	Shrubland, grassland

Montane scrub vegetation commonly is an intermediary phase in sites that have been disturbed, with forest or tussock grassland being the later successional stage (Primack, 1978). Scrub vegetation goes through a 75-year period of alteration before reaching a final stage dominated by *Dracophyllum longifolium* and *Phyllocadus alpinus*, and low subalpine forest goes through a 200-year intermediary scrub phase before the trees regain their dominance (Calder and Wardle, 1969). Alterations in the shrub populations in the grasslands are slow in the area (Primack, 1978). Throughout the study by (Primack, 1978), beech forest at Cass made an approximate expansion of two metres into the adjoining grasslands (16-year study). The shrubs and herbs of the grassland die during the formation of the beech canopy. It will take thousands of years, if grazing continues, before forests will resume the dominance in the Cass District. However, this may not be the case in the Cass Research Area. Stock numbers are low in this area, and regeneration of scrub communities appears to be relatively fast. The following photos show the approximate succession rate that occurs at Cass from 1915 to 2001 (Figure 2.3, Figure 2.4, and Figure 2.5). From 1915 to 2001, the proportion of shrubs and forest increased relatively quickly. It appears that the erosion in Sugarloaf does not change much over time, although there is evidence of students and staff, from the University of Canterbury, enhancing erosion by running down the screes (D. Norton, pers. comm.).

Figure 2.3 Sugarloaf and surrounding vegetation in 1915 (photo: C. Foweraker)

Figure 2.4 Sugarloaf and surrounding vegetation in 1978 (photo: D. Norton)

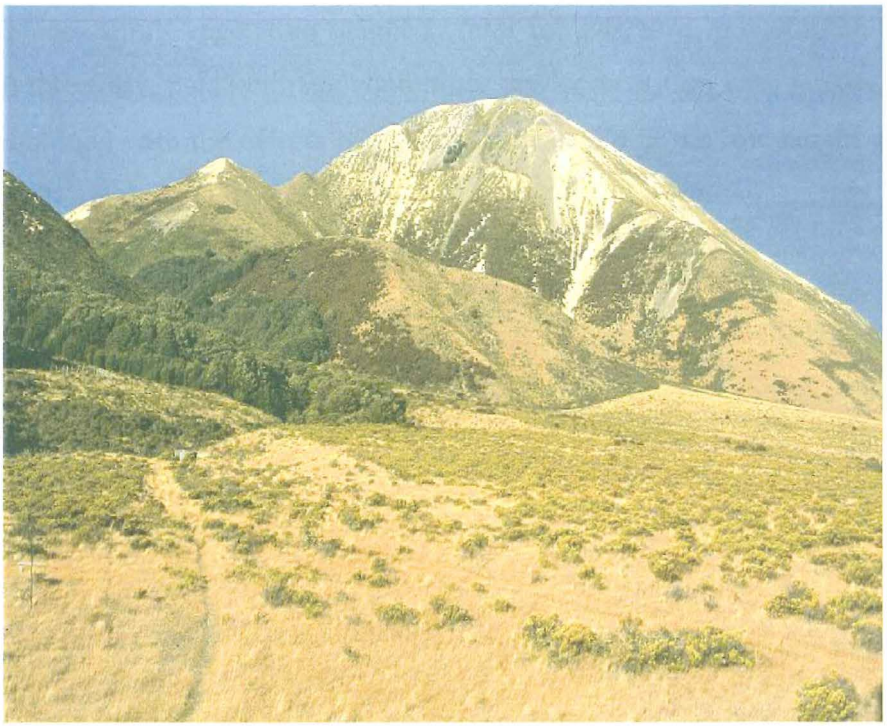

Figure 2.5 Sugarloaf and surrounding vegetation in 2001 (photo: D. Norton)

2.7 Current vegetation

The current vegetation of the Cass study area comprises grasslands, scrub, forest, and mire vegetation. Chapter Three discusses these vegetation types in detail, but below are brief descriptions of the main influences on these vegetation types. Figure 2.5 gives a visual picture of the current stages of regenerated vegetation.

Present vegetation at Cass (grassland, shrubland, scrub, forest, and swamp) is thought to result from past disturbances, such as fire, grazing, and natural deposition of gravels (Burrell, 1965; Wardle, 1969; Dobson and Burrows, 1977). Disturbances are necessary for the initial establishment of grass and shrub vegetation. (Primack, 1978) found that grazing does not have a consistent influence on shrub survival over a 16-year period. It was found that shrubs establish themselves in sheep and rabbit exclosure plots. This indicates that a major disturbance is not always necessary for shrub establishment (Primack, 1978). Primack's (1978) study did indicate that grazing resulted in an increase in recruitment rates of shrubs in relation to non-grazing. Possible reasons for this are that grazing animals may reduce the growth and competitive ability of the grasses, remove plant matter thereby allowing light to reach the soil surface, and open the soil surface with their feet thereby increasing the number of microsites suitable for seed germination. However, grazing did

appear to depress shrub vegetation height at least for *Discaria toumatou* and *Coprosma* species. Soil infertility, harsh climate conditions, and competition with grasses for limited resources combined with the effects of grazing, play a role in the low height growth rates (Primack, 1978).

Chapter 3 Vegetation description

3.1 Introduction

A clear understanding of the vegetation communities in the study area is paramount when studying possum movement, diet, and resource selection, particularly in relating species to a particular habitat or diet preference in a community.

The vegetation of the study area consists of patches of swamp, grassland, shrubland, scrub and forest. This mosaic of successional vegetation mirrors the history of Cass, especially the influence of burning and farming. The vegetation pattern consists of relatively distinct patches, although within these patches there is a high level of variability in internal composition and structure. Cockayne and Foweraker, (1915) discuss the different vegetation types in the Cass area in 1915.

The aim of this chapter is to describe the current vegetation pattern of the study area to provide a quantitative assessment of the vegetation composition. This will provide a basis for enabling a quantitative study on possum resource selection at Cass.

3.2 Methods

3.2.1 Vegetation data

In autumn (March 2001), 84 unbounded plots were established in the study area. Seventy-two recce plots were extracted from a 1ha × 1ha grid system (Figure 3.1). Recce plots were located 200m apart at 100m intervals along north-south transect lines. Four recce plots were specifically located in gullies to increase the number of plots in this under-represented physiographical type (Figure 3.1). Eight recce plots were also located in areas along north-south gridlines between primary transect lines where high possum activity was recorded throughout the previous year (Chapter 4), (Figure 3.1). These extra recce plots were chosen to give a better vegetation description in the areas with high possum activity.

The recce procedure (Allen, 1992) was used to assess vegetation composition and structure. Forest recce plots were 10m radius ($314m^2$). Scrub, shrubland, grassland and

swamp recce plots were 5m radius (79m^2). Cover abundance was recorded for established vascular plant species using four strata: ground (0-1m), scrub/shrub (1-5m), sub-canopy (5-10m) and canopy (10-15m). Abundance cover classes comprised <1, 1-5, 5-10, 11-25, 26-50, 51-75 and 76-100%. Drainage was recorded as good, medium or poor. Physiography was recorded as ridge, face, gully or terrace. Aspect was measured with a compass and slope measured with a clinometer. Within each recce plot, the cover abundance of all vascular plant species was recorded for up to four strata, and the height range for each stratum was recorded.

The recce plots were processed in RECINT within PC-RECCE computer package (Hall, 1992). This program summarises the data to give one importance value per species per plot. This is done using an analysis procedure which assembles information on stratum height and species cover. Weights were independently determined for every stratum using $\log_{10}$ of stratum height, and species cover was then multiplied by these weights and summed over all strata.

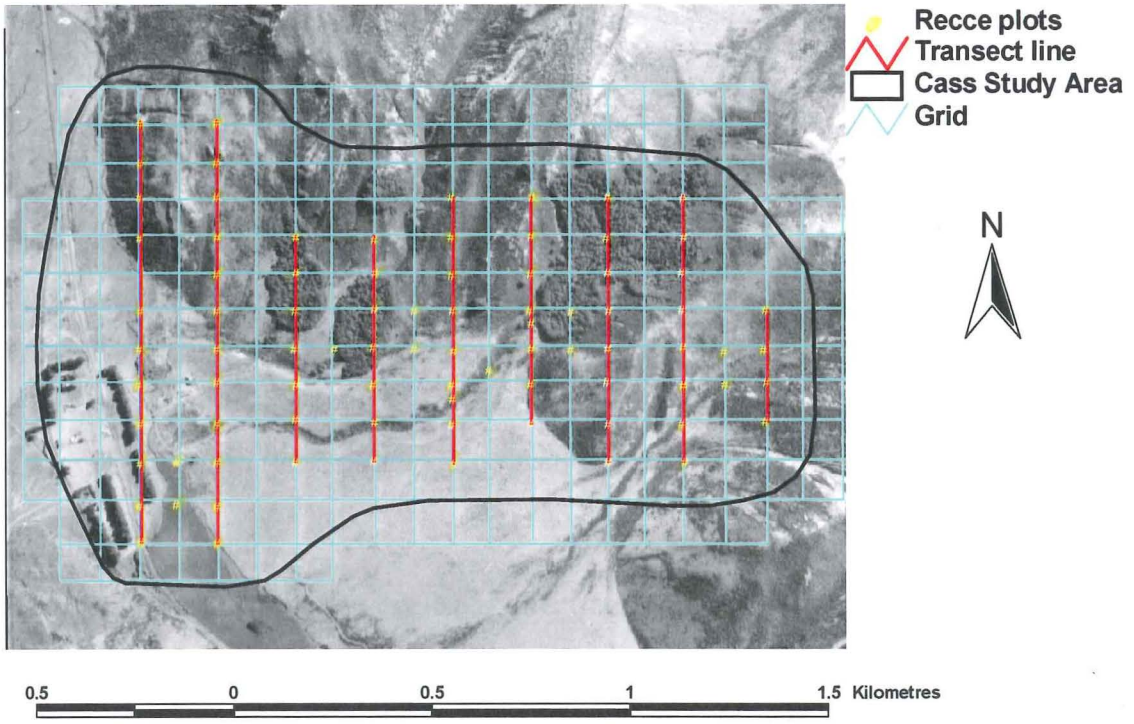

Figure 3.1 Location of grid system, transect lines, and recce plot locations for vegetation survey at Cass study area.

3.2.2 TWINSPAN (Two-Way Indicator Species Analyses)

The vegetation data collected were classified by indicator species analyses, using the program TWINSPAN (Hill, 1979). TWINSPAN is a multivariate analysis program that constructs a classification of the samples based on floristic composition. A two-way table is obtained from the classification which shows the species' synecological interaction as concisely as possible. TWINSPAN is able to classify RECCE plot data using a polythetic divisive algorithm.

The TWINSPAN program classifies community ecological data by dividing the whole data set progressively into smaller groups using successive reciprocal averaging ordinations (Hall, 1992). Divisions stop at a preselected level of subdivisions. TWINSPAN uses species indicator analysis to show which species most distinguish one community from another. The options used in TWINSPAN for pseudo-species cut levels were: 0.0, 2.0, 5.0, 20.0, and 50.0. After examining the divisions the fourth level was used for classification. The findings are presented in a two-way species-by-plot table of rescaled species' importance values (Hall, 1992).

3.2.3 Detrended Correspondence Analysis (DCA)

Ordinations are multivariate techniques which arrange sites based on their floristic composition along axes of floristic dissimilarity (ter Braak and Looman, 1987). Ordinations order vegetation samples (plots) in two-dimensional space, grouping plots that have similar species composition close together, and plots that are dissimilar further apart. The environmental variables that have influenced the floristic relationships between plots can then be examined (ter Braak and Looman, 1987).

Two types of ordinations can be used: direct and indirect ordinations. Direct ordination occurs when information about the floristic relationship between plots is constrained by information on environmental variables. Indirect ordinations result when floristic data is analysed without reference to environmental data (Whittaker, 1978; ter Braak, 1987). Indirect ordination will be used at Cass as no assumptions are made about which environmental factors determine vegetation pattern. Comparisons between vegetation

patterns and environmental data will then be undertaken once the ordination has been calculated.

Detrended Correspondence Analysis analyses species-environment relationships using community composition data and associated habitat measurements. This analysis removes non-linear dependencies between axes (Hill and Gauch, 1980) and is proficient with removing one or more ordination axes for showing unimodal response curves with respect to the axes (ter Braak, 1985). This type of analysis is an indirect gradient analysis where only the floristic data is analysed (Whittaker, 1978; ter Braak, 1987). Detrended Correspondence Analysis was undertaken in CANOCO and default options were used in the analysis. Axes were compared with environmental data after analysis using Pearson product moment correlations.

3.2.4 Diversity Indices (DI)

Diversity indices are commonly used when describing vegetation community structure (Begon *et al.*, 1996). Berger-Parker dominance index and Shannon DI are robust tools for describing community abundance patterns and species richness. Berger-Parker index has poor discriminant ability, low sensitivity to sample size and describes dominance. Shannon DI has moderate discriminant ability, moderate sensitivity and describes species richness and dominance (Magurran, 1988). Discriminant ability relates to how well the effectiveness of a diversity measure discriminates between sites that are not overly dissimilar. The sensitivity of the test relates to the sensitivity to sample size. Species richness and species dominance is an index that is related to sampling intensity (Magurran, 1988). An increase in sample size generally increases species richness.

3.2.4.1 Berger-Parker Dominance Index

Calculating the Berger-Parker DI involves separating species into each community type (from TWINSPAN) and the total vegetation plots in which each species occurred. Calculation of the index involves the number of times each species occurs in each community (N), and the species that occurs most in each community (N_{max}). The equation is:

$$d = \frac{N_{max}}{N}$$

The larger d indicates the community having a greater degree of dominance of species occurring, which implies less diversity.

3.2.4.2 Shannon diversity index

For each identified community (from TWINSPAN) each species present (S) and the total number of times it occurred in each vegetation plot (N) are indicated. Shannon DI (proportional abundance, *pi*) is calculated by:

$$pi = \frac{ni}{N}$$

From *pi*, the Shannon DI (H') is calculated:

$$H' = -\sum p_i \ln p_i$$

Higher H' values indicate higher species diversity.

3.3 Results

3.3.1 Plant communities

Six vegetation types were identified in the TWINSPAN classification of the complete vegetation data (Figure 3.2) and are mapped in Figure 3.3. The first dichotomy in the classification distinguishes between wet and dry areas with the indicator species being *Typha orientalis* for the swamp. No more divisions were made for the swamp community (Community 1). The second division within the dry land communities separated forest communities from scrub, shrubland, and grassland. *Nothofagus solandri* is the indicator species for the forest community. No more divisions were made within the forest community (Community 6). *Agrostis capillaris* is the indicator species for the scrub, shrubland, and grassland communities. The third division separated grassland and shrubland communities from scrub communities. Indicator species for grassland and shrubland is *Agrostis capillaris. Blechnum penna-marina, Hebe venustula, Gaultheria*

antipoda and *Poa colensoi* are indicator species for the two scrub communities. The fourth division separates the grassland community from the shrubland community. Indicator species for the grassland community (community 2) are *Achillea millefolium* and *Carex goyenii. Taraxacum officinale* is the indicator species for the shrubland community (Community 3). The fifth dichotomy distinguishes between the two scrub communities with *Festuca novae-zelandiae, Ozothamnus leptophylla, Agrostis capillaris* and *Acaena inermis* as indicator species for scrub 1 community (Community 4), and *Celmisia spectabilis* and *Dracophyllum* species being indicator species for scrub 2 community (Community 5).

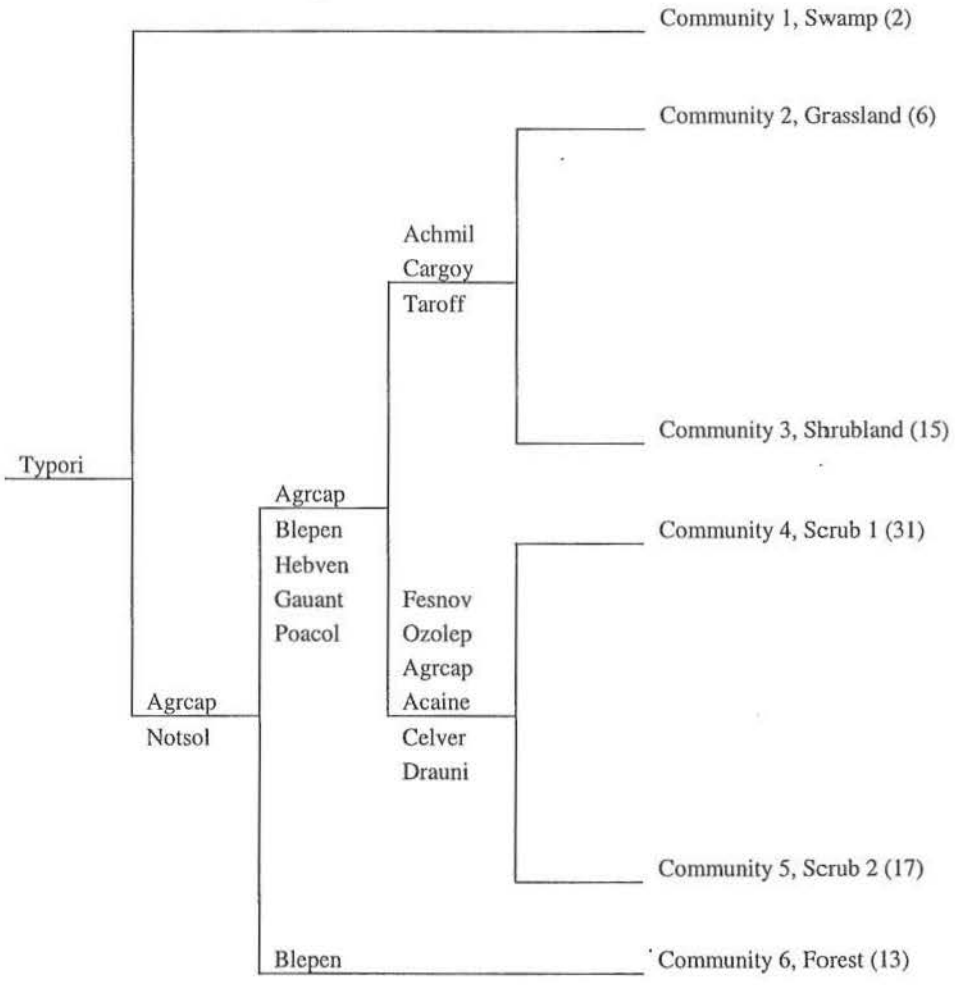

Figure 3.2 Dendrogram from the ISA classification shows indicator species and relationships between the six communities. Species codes are the first three letters of the generic and specific names for each species (See Table 3.3 for full names)

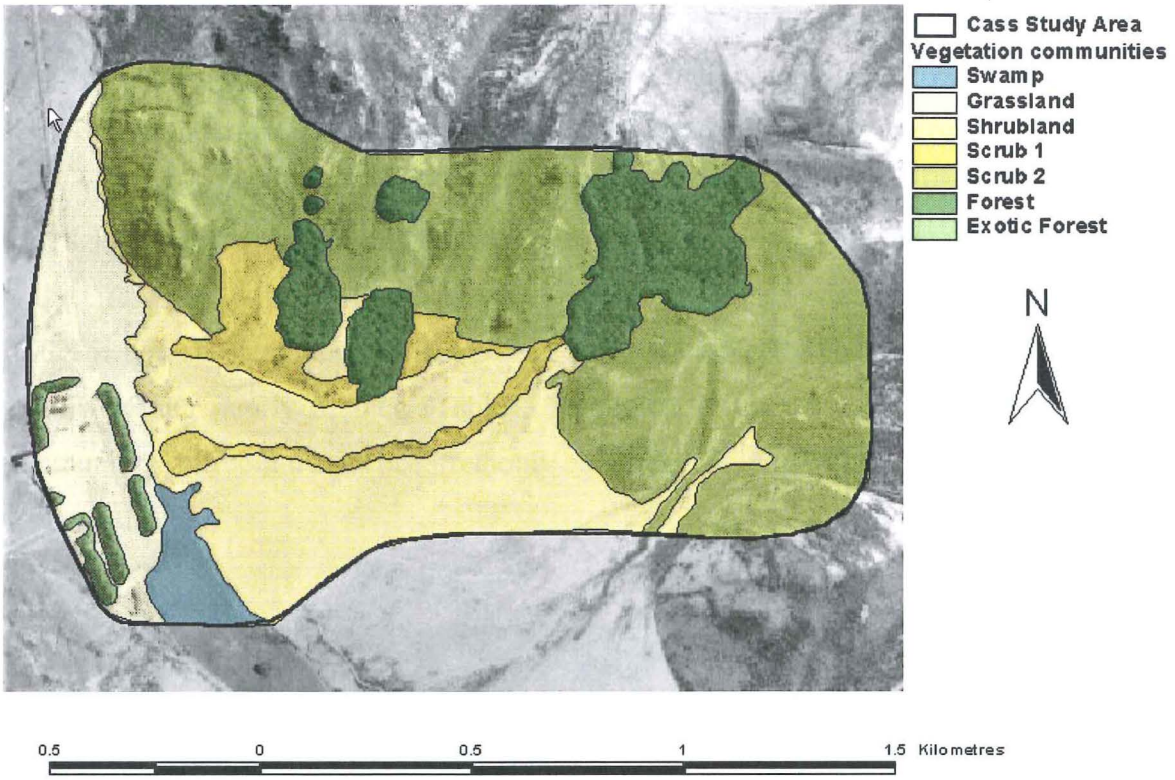

Figure 3.3 Cass study area vegetation map showing the distribution of the six identified vegetation types

To aid community interpretation, percent cover abundance for main plant species (present in ≥60% of plots for any one community) is presented in Table 3.2. Community naming follows the Atkinson (1985) system and are described below. A species list for Cass study area is in Appendix one: vegetation species list.

1. *Typha orientalis* swamp (2 plots) is the second least dominant vegetation community present at Cass (Table 3.3), and is located adjacent to the train tracks (Figure 3.3). This vegetation community is comprised of only one species (*Typha orientalis*) with high cover abundance in both tiers (Table 3.2). Although no other plant species were recorded in the two plots, two *Salix fragilis* (willow) were observed along the swamp edge of the Grassmere Stream close to Lake Sarah. Species richness was low, with one species (100% native species) per plot (Table 3.3). Plots are typically gently sloping (1.0°) to the south-west and poorly drained (Table 3.1). Figure 3.4 gives a view of the vegetation community. This community occurred only on terraces (Figure 3.11).

Figure 3.4 Swamp community (photo: E. de Zwart, 2001).

2. *Agrostis capillaris-Carex goyenii* grassland (six plots) is located on alluvial surfaces between Grassmere Stream and the train tracks (Figure 3.3). This community is dominated by *Carex goyenii, Festuca novae-zelandiae, Agrostis capillaris*, and *Anthoxanthum odoratum* in only one tier (Table 3.2). Shrubs are sparse and comprised of *Ozothamnus leptophylla, Hebe venustula* and *Discaria toumatou* (Table 3.2). There is a diverse herbaceous flora amongst the taller grasses and sedges. Species richness is the third lowest among the vegetation communities present at Cass, comprising an average of 10 ± 1.3 species per plot (Table 3.3) with 35% of these native (Table 3.3). This community occurs on level sites (1° slope; Table 3.3), with good drainage (Table 3.1). The Berger-Parker Index is high and Shannon DI the second lowest (Table 3.3). Figure 3.5 gives a visual view of the vegetation community. This community occurred only on terraces (Figure 3.11).

Figure 3.5 Grassland community (photo: E. de Zwart, 2001)

3. *Discaria toumatou-Ozothamnus leptopyhlla/Agrostis capillaris-Festuca novae-zelandiae-Anthoxanthum odoratum* shrubland (15 plots) is located across the main fans of Cass Hill and Sugarloaf (Figure 3.3). Dominant shrub species in this community are *Discaria toumatou*, and *Ozothamnus leptophylla* (Table 3.2). Dominant grass and herbaceous species include *Festuca novae-zelandiae, Agrostis capillaris, Anthoxanthum odoratum*, *Leucopogon fraseri*, and *Taraxacum officinale* (Table 3.2). Species richness is the third highest of all the vegetation communities present in the study area with 12.0 ± 0.9 species per plot with 70% of native species (Table 3.3). Berger-Parker dominance index was low (0.083) and Shannon diversity index was high (12.515) (Table 3.4). Soil drainage was good (Table 3.1). Plots had a general slope of 6.6 ± 1.5° and are south-west facing (Table 3.3). Figure 3.6 gives a view of the vegetation community. This community occurred on terraces and lower hill faces (Figure 3.11).

Figure 3.6 Shrubland community (photo: E. de Zwart, 2001).

4. *Discaria toumatou-Coprosma propinqua-Ozothamnus leptophylla/Festuca novae-zelandiae* scrub (31 plots) is found on parts of the lower slopes of Cass Hill and Sugarloaf (Figure 3.3). This community is dominated by scrub species (*Discaria toumatou, Ozothamnus leptophylla, Coprosma propinqua,* and *Hebe venustula*) in both strata (Table 3.2). *Hypochoeris radicata, Agrostis capillaris, Anthoxanthum odoratum,* and *Leucopogon fraseri* are also abundant in this community. Species richness was high comprising 17.4 ± 0.7 species per plot, with 76% of native species (Table 3.3), and has a high species diversity index (Shannon DI = 14.125) and a low dominance index (Berger-Parker DI = 0.056) (Table 3.4). Soil drainage was relatively good with 97% of vegetation plots having good drainage and 3% of vegetation plots having medium drainage (Table 3.1). Plots had a general slope of 13 ± 1.4° and were generally south west facing (Table 3.3). Figure 3.7 gives a view of the vegetation community. This community occurred on all physiographical types (Figure 3.11).

Figure 3.7 Scrub 1 community (photo: E. de Zwart, 2001).

5. *Hebe venustula-Dracophyllum* species-*Discaria toumatou/Celmisia spectabilis-Blechnum penna-marina* scrub (17 plots) is found on the higher slopes of Cass Hill and Sugarloaf (Figure 3.3). This community is dominated by scrub species (*Hebe venustula, Discaria toumatou,* and *Dracophyllum* species) in both tiers, with some herbaceous and dwarf shrub species present (*Hypochoeris radicata, Raoulia subsericea, Leucopogon fraseri, Gaultheria antipoda*) and one grass species (*Poa colensoi*) (Table 3.2). Species richness was second highest (17.0 ± 0.8) with 84% of native species (Table 3.3). Species dominance was low (Berger-Parker DI = 0.56) and species diversity high (14.928). Vegetation plots had a slope of 23.4 ± 1.6° and are south west facing (Table 3.3). Figure 3.8 gives a visual view of the vegetation community. This community occurred on all physiographical types (Figure 3.11).

Figure 3.8 Scrub 2 community (photo: E. de Zwart, 2001).

6. *Nothofagus solandri* forest (13 plots) is found in small areas along gullies that are present on the slopes of Cass Hill and Sugarloaf Hill (Figure 3.3). This vegetation community is dominated by *Nothofagus solandri* (Table 3.2). *Coprosma propinqua* is scattered throughout the forest in low numbers, and *Hebe venustula* is frequently found at the forest edge. *Uncinia clavata, Hypolepis millefolium, Blechnum penna-marina, Polystichum vestitum, Blechnum fluviatile, Hypochoeris radicata,* and *Coprosma propinqua* are found on the stream sides within the forest. The stream sides and slips have a higher diversity of species than the rest of the forest. This community comprised four tiers with a maximum height of 20 metres. Species richness was low consisting of 4.9 ± 1.4 species per plot with 91% of native species, a high dominance index (Berger-Parker DI = 0.056) and a low diversity index (Shannon DI = 11.024) (Table 3.3). Plots have a slope of 14.7 ± 2.2°, are south facing (Table 3.3) and have good drainage (Table 3.1). Figure 3.9 gives a view of the vegetation community. This community occurred on all physiographical types (Figure 3.11).

Figure 3.9 Native forest community (photo: E. de Zwart, 2001).

7. *Pinus radiata* forest (no plots). As no vegetation plots were sampled, the exotic shelter belt area is not included in Figure 3.2, but these are mapped in Figure 3.3. The exotic trees (*Pinus radiata*) were planted as wind breaks for Cass settlement, and the area (Table 3.3) and presence of the exotic trees were derived from the aerial photo (Figure 3.3). This community is the smallest vegetation community present at Cass. Slope and aspect of the exotic forest is similar to the grassland community. Herbaceous plants are present under the pine trees, but presence is infrequent.

Figure 3.10 Exotic forest shelterbelt (—— circles the exotic forest) (photo: E. de Zwart, 2001).

Table 3.1 Percentage of plots in different soil drainage classes for each vegetation community at Cass study area.

Community type	Good	Medium	Poor
Swamp	0	0	100
Grassland	100	0	0
Shrubland	100	0	0
Scrub 1	96.8	3.2	0
Scrub 2	100	0	0
Forest	100	0	0

Table 3.2 Ordered species percent cover abundance matrix for those species present in ≥60% of plots in any one community. – species with <1% cover; + species present in <60% of plots in community.

Species	Swamp	Grassland	Shrubland	Scrub 1	Scrub 2	Forest
Typha orientalis	176					
Nothofagus solandri						182
Blechnum penna-marina					14	
Coprosma propinqua				17		
Hebe venustula				6	23	
Dracophyllum species					21	
Gaultheria antipoda					+	
Celmisia spectabilis					12	
Poa colensoi					3	
Leucopogon fraseri			+	2	3	
Hypochoeris radicata				6	+	
Raoulia subsericea					+	
Ozothamnus leptophylla			9	14		
Discaria toumatou			15	29	22	
Carex goyenii		11				
Taraxacum officinale			-			
Festuca novae-zelandiae		6	26	14		
Trifolium repens		-				
Achillea millefolium		+				
Agrostis capillaris		14	20	5		
Anthoxanthum odoratum		6	5	3		

Table 3.3 Table showing aspect, slope, tiers, area, total species present, species richness, Berger-Parker DI, and Shannon DI results for the seven communities identified at Cass study area.

Variables	Swamp	Grassland	Shrubland	Scrub 1	Scrub 2	Forest	Exotic Forest
Aspect	229.0	284.5	237.7	219.5	206.4	181.4	229.0
Slope (°)	1.0	1.0	6.6±1.5	13.0±1.4	23.4±1.6	14.7±2.2	1.0
Tiers (1-4)	2	1	1	2	2	4	-
Area (ha)	4.6	20.8	45.3	12.3	86.8	21.8	3.7
Total species	1	26	46	63	45	33	-
Species richness	1	10.2±1.3	12.0±0.9	17.4±0.7	17.0±0.8	4.9±1.4	-
Berger-Parker DI (*d*)	1	0.098	0.083	0.056	0.056	0.203	-
Shannon DI (*H*)	0	10.2	12.5	14.1	15.0	11.0	-
Native species (%)	100	35	70	76	84	91	-

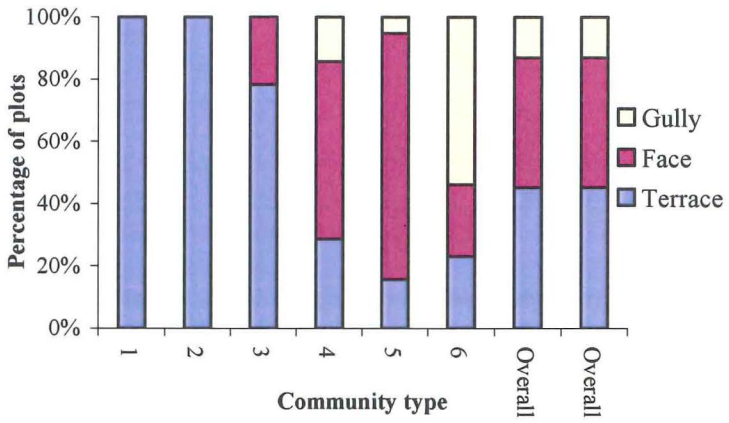

Figure 3.11 The percentages of different physiographical features within the different community types, and total percentage over all the communities.

3.3.2 Ordination of plots and species

Noteworthy correlations were identified in the ordination of the plot scores with slope and aspect (Table 3.4, Table 3.5).

The DCA ordination (Figure 3.12) showed that plots with steep slopes occurred at the top left (scrub 1, scrub 2, and forest communities), and those with gentle slopes are towards the bottom left (grassland and shrubland communities) of the plot ordination. The sum of all the eigenvalues is 4.537 for Figure 3.12, with axis 1 explaining 21% of all variation in the data and axis 2 explaining 10% of the variation. Plots present on terraces tend towards the left of the plot ordination, plots with hill faces tend towards the middle, and plots with gullies present occur on the right side (Figure 3.12). Drainage decreased from right to left, indicating that grassland has the worst drainage, although the correlation was weak.

The aspect of the study area ranges from south facing vegetation communities to west facing. Table 3.3 shows which direction the vegetation communities are facing, with the forest community facing south. The scrub 1, scrub 2, exotic forest, swamp, and shrubland all are south-west facing community, and the grassland community is west facing.

Table 3.4 Correlations between environmental variables and ordination axes following DCA ordination without *Typha orientalis*.

	Aspect	Slope	Drain
Axes 1	-0.3160	-0.0346	-0.0664
Axes 2	-0.2334	0.3715	-0.0706

Table 3.5 Correlations between environmental variables and ordination axes following DCA ordination without *Typha orientalis* and with the 'down-weighting' of rare species.

	Aspect	Slope	Drain
Axes 1	-0.3140	-0.0405	-0.0726
Axes 2	-0.1743	0.3895	-0.0733

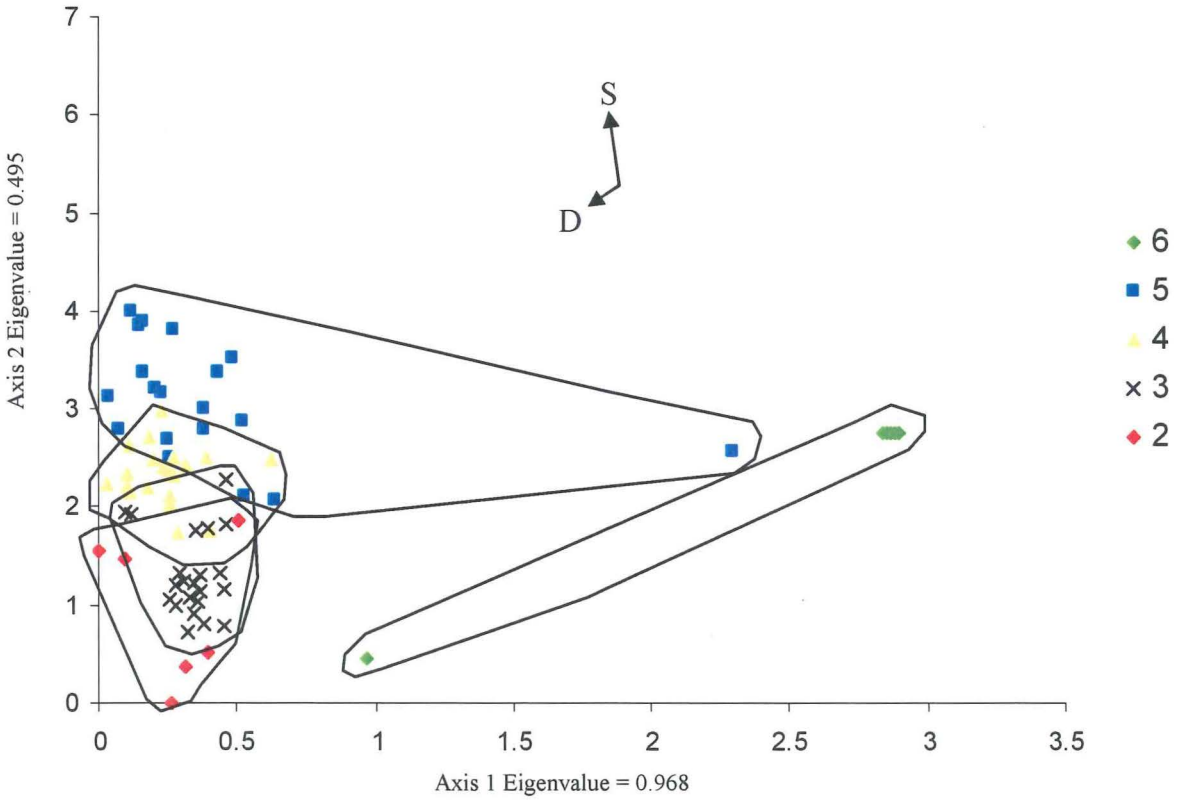

Figure 3.12 Axes 1 and 2 of the DCA plot ordination with ISA communities superimposed. The directions of maximum correlations with environmental variables are shown (length of line proportional to r value). A, aspect; D, drainage; P, physiography; S, slope; 2, Grassland; 3, Shrubland; 4, Scrub 1; 5, Scrub 2; 6, Forest.

The ordination for plots with the 'down-weighting' of rare species (Figure 3.13) option in the program DECORANA showed a different pattern from that of the ordination without the 'down-weighting' of rare species option (Figure 3.12). This ordination clustered the grassland, shrubland, scrub 1, scrub 2, and forest closer together. The sum of all

eigenvalues is 5.791, with axis 1 explaining 17% of all variation in the data and axis 2 explaining 9% of the data. Compared to Figure 3.12, the forest community did not differ much on the inside (for example the stream edges were similar to the other parts of the forests), and was very similar to the other vegetation communities (not including the swamp community). The grassland, shrubland, scrub 1, and scrub 2 plots, were separated further along axis 1 in Figure 3.13 than in Figure 3.12. The scrub 2 community was more similar with the 'down-weighting' of rare species, while the scrub 1, shrubland, and grassland community appear to be less similar (Figure 3.12 and Figure 3.13).

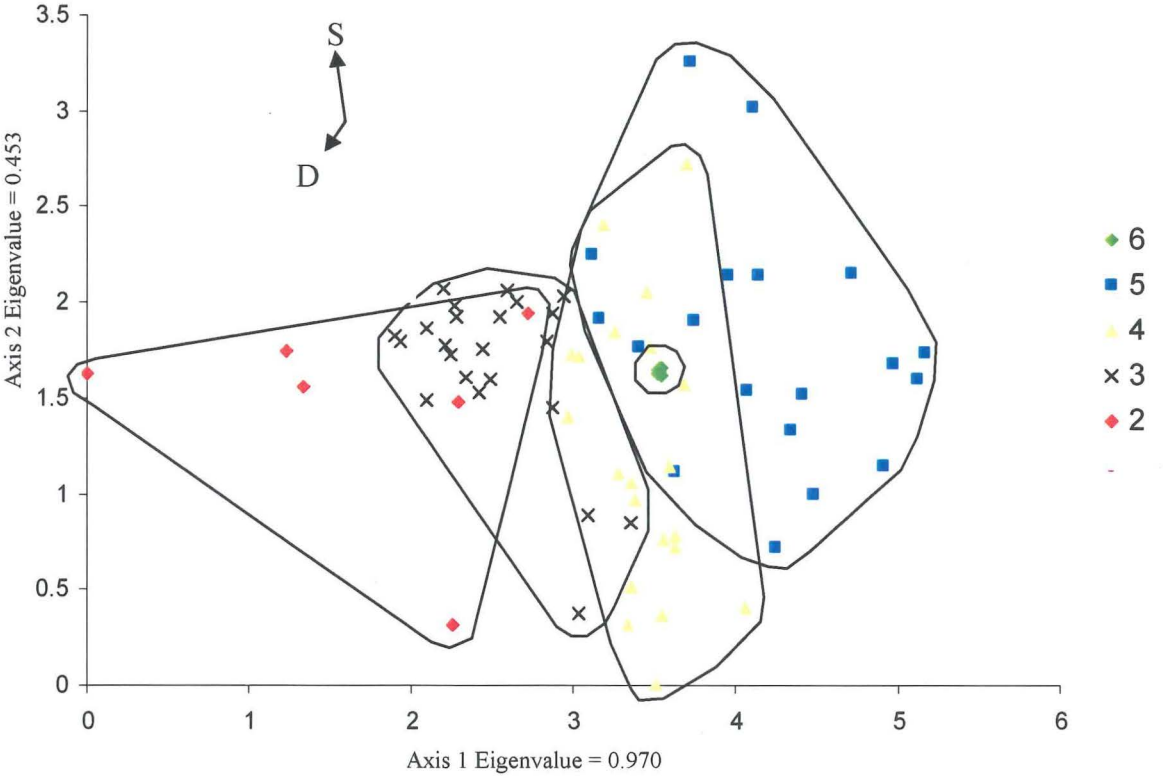

Figure 3.13 Axes 1 and 2 of the 'downweighting option of rare species' DCA plot ordination with ISA communities superimposed. The directions of maximum correlations with environmental variables are shown (length of line proportional to r value). A, aspect; D, drainage; P, physiography; S, slope; 2, Grassland; 3, Shrubland; 4, Scrub 1; 5, Scrub 2; 6, Forest.

Similar patterns are seen in the species ordination without *Cytisus scoparius* (Figure 3.14), with species occurring on steeper slopes present in the top right of the species ordination. *Cytisus scoparius* was not included in the ordination because when it was included the ordination showed that it was very different from the other plant species, thus reducing the level of understanding of the relationship between the other species present in the ordination. Species mainly present in gullies tend towards the bottom right corner of the

species ordination, and those occurring mainly on terraces occurring in the bottom left corner. The sum of all eigenvalues is 4.537, with axis 1 explaining 21 % of all variation in the data and axis 2 explaining 10 % of the variation.

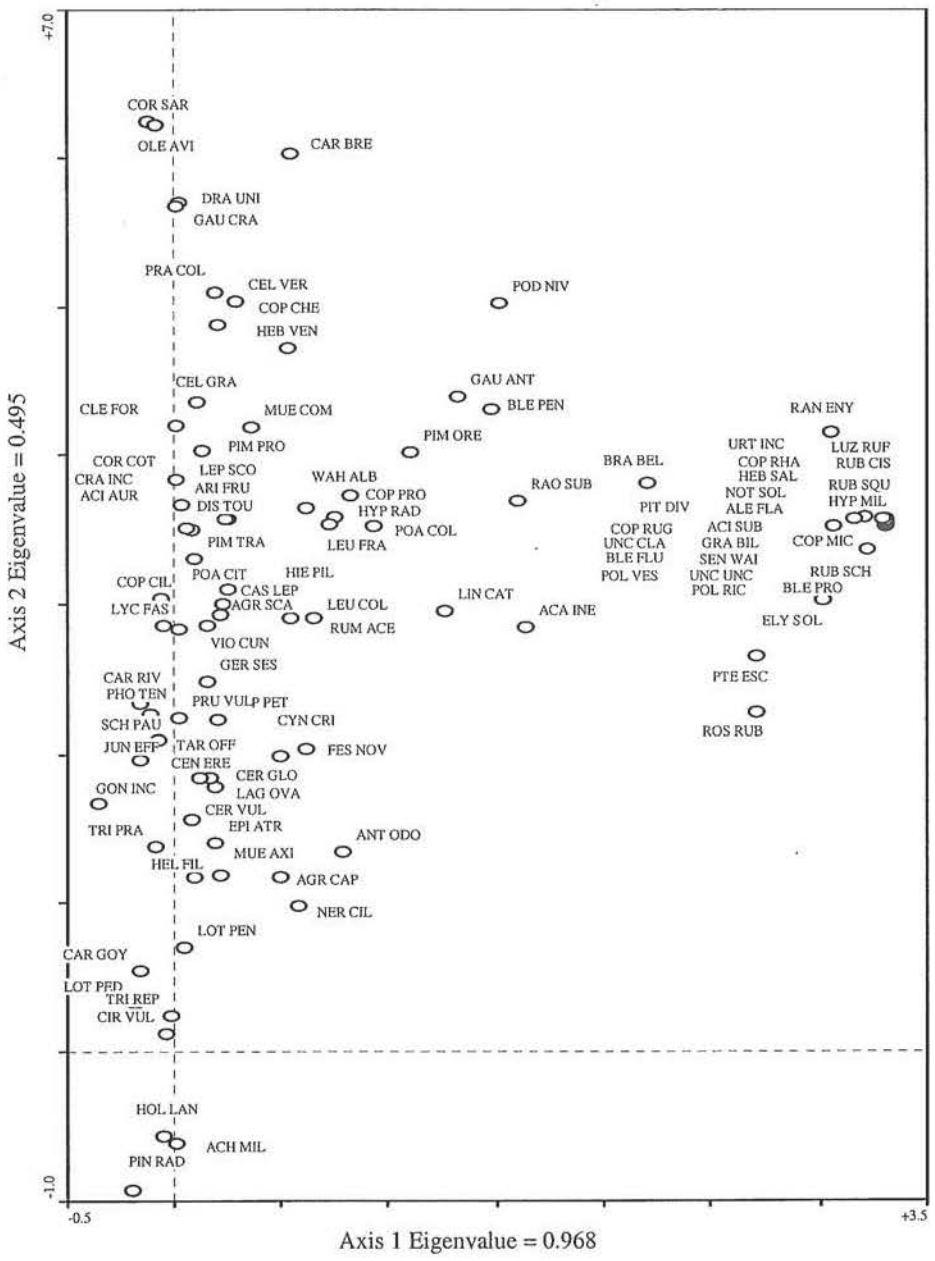

Figure 3.14 Axes 1 and 2 of the DCA species ordination. The positions of species have been plotted without broom and raupo. Species names are abbreviated and comprise the first three letters of the generic name and the first three letters of the specific name (Appendix 1 has a species list of vegetation present at Cass).

There appears to some variation between the 97 species that were found in the study area (excluding *Cytisus scoparius*), with species that were mainly found in the forest community, such as *Nothofagus solandri, Polystichum vestitum*, and *Coprosma*

microcarpa found at the right side of the ordination (Figure 3.14). *Pinus radiata* was found at the bottom left of the ordination with grassland species such as *Carex goyenii*, *Achillea millefolium*, and *Holcus lanatus* closest to it. *Pinus radiata* was found in the grassland plots that were next to the exotic forest. Species at the top left corner of the ordination came from the scrub communities, for example *Dracophyllum* species, *Coriaria sarmentosa*, and *Olearia avicenniifolia*. Plant species in the middle of the ordination belong to the shrubland community, for example *Poa cita*, *Hebe venustula*, and *Agrostis capillaris*, with other plant species from some other vegetation communities nearby. Many plant species that were found at Cass were found in two or more vegetation communities (Appendix one) which explains why most of the species are found close together in the middle of the ordination.

Without *Cytisus scoparius* and with the 'down-weighting' of rare species the ordination (Figure 3.15) resulted in a similar pattern to that in Figure 3.14. The sum of all eigenvalues is 5.791, with axis 1 explaining 17 % of all variation in the data and axis 2 explaining 9 % of the variation. There appears to be some variation between the 97 species that were found in the study area (excluding *Cytisus scoparius*), with the similar species indicating the forest community at the top right corner of the ordination. At the bottom left corner of the ordination *Pinus radiata* appears to have a similar association with *Holcus lanatus* and *Achillea millefolium*. The scrub communities are again at the top right corner of the ordination containing most of the species that were found in the same place in Figure 3.14, which also occurs with the species in the middle of the ordination.

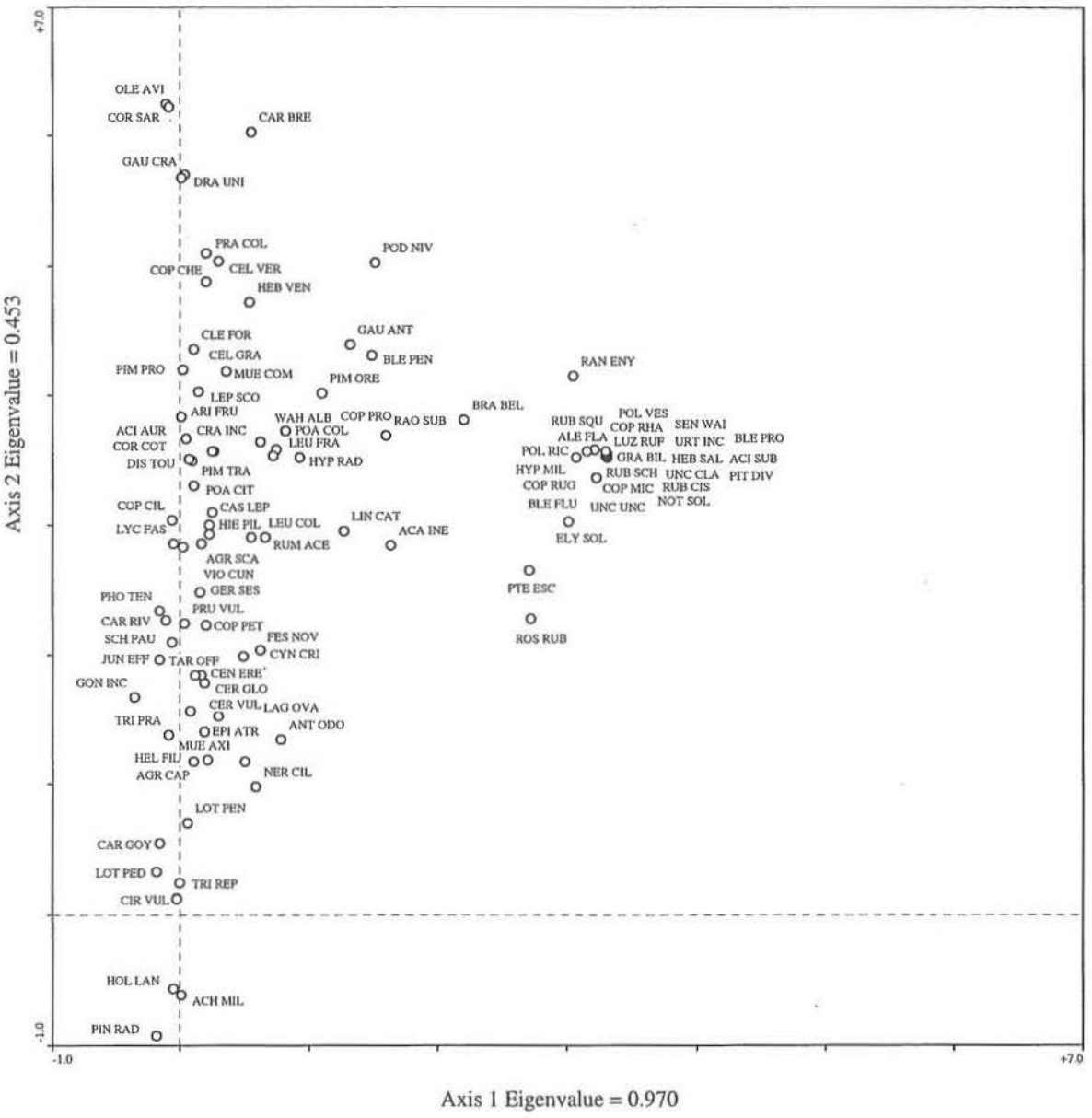

Figure 3.15 Axes 1 and 2 of the 'downweighting option of rare species' DCA species ordination. The positions of species have been plotted without broom and raupo. Species names are abbreviated and comprise the first three letters of the generic name and the first three letters of the specific name (Appendix 1 has a species list of vegetation present at Cass).

3.4 Discussion

The establishment and maintenance of shrubland and scrub areas in New Zealand has probably resulted from disturbances such as fire, grazing, and natural deposition of gravels (Burrell, 1965; Burrows, 1969; Wardle, 1969; Dobson and Burrows, 1977). Also, landforms and soil types are environmental factors that are known to influence vegetation and individual plant patterns in New Zealand (Wardle, 1977; Wardle, 1980; Smith and Lee, 1984; Stewart and Harrison, 1987; Norton and Leathwick, 1990). This study area is

consists mainly of yellow-brown earths, which are strongly leached and occur on the fans and terraces. The physiography of the area has been determined by historical glaciers, faulting, differential uplift, and glaciation (Soons, 1977), and present day factors include active erosion (Gage, 1977; Shanks *et al.*, 1990). Before European settlement, short-tussock grasslands and regenerating shrubland replaced forests after the Polynesian fires. Europeans continued to burn areas of grassland and shrubland to create suitable grassland for pastoral farming.

Current vegetation patterns in the Cass Area are similar to those recorded in both the early 1910s (Cockayne and Foweraker, 1915) and the 1990s (Shanks, *et al.*, 1990). In 1915, the forest community did not have a dense understory (Cockayne and Foweraker, 1915), which is similar to the present time, and now that sheep have been present at Cass for many years, there are now areas where there is no undergrowth. Cockayne and Foweraker (1915) describe four shrubland communities: *Cassinia* (now *Ozothamnus* species) open shrubland, *Discaria* (wild-irishman) thicket, *Leptospermum* (manuka) thicket, and river-terrace and debris scrub. The latter three shrubland communities are classified as scrub communities in this study. (Cockayne and Foweraker, 1915) also describes low tussock grassland, swamp, river-bed, and forest vegetation communities.

The open *Cassinia* shrubland is a common feature in the lowland and montane areas in New Zealand, especially in areas where forests close to the coast have been removed by humans (Cockayne and Foweraker, 1915). *Cassinia* species are quick-growing plants of ericoid form, are tolerant of drought, and reproduce many seeds with a high germination rate that are wind-dispersed resulting in the seeds being able to be transported over large distances. Other species that Cockayne and Foweraker (1915) found in this vegetation community includes: *Discaria toumatou*, *Melicytus alpinus*, *Leptospermum scoparium*, *Corokia cotoneaster*, *Gaultheria depressa*, *Leucopogon colensoi*, and *Dracophyllum uniflorum*. The ground cover of this shrubland included the following species: *Blechnum penna-marina*, *Poa colensoi*, *Festuca novae-zealandiae*, *Acaena sanguisorbae* var. *pilosa*, *Viola cunninghamii*, *Pimelea prostrate*, *Leucopogon fraseri*, *Celmisia longifolia*, *Raoulia subsericia*, *Microseris scapigera*, and *Senecio bellidioides* var. *glabratus* (Cockayne and Foweraker, 1915). The shrubland community in 2001 has almost the same dominant species with *Discaria toumatou, Ozothamnus leptopyhlla, Agrostis capillaris, Festuca*

novae-zealandiae, and *Anthoxanthum odoratum* as the dominant species, which is also similar to 1990 vegetation (Shanks, *et al.*, 1990).

The *Discaria* thicket in 1915 was made almost entirely of *Discaria toumatou* and was of an average height of 1.2 metres and grew openly (Cockayne and Foweraker, 1915), rather than growing thickly together as it does now. Other plant species were not very common in this area, except sometimes the liane *Clematis marata* (Cockayne and Foweraker, 1915). *Discaria* thickets are common in the South Island and are quite often found in areas that are dry river-terrace and stony fans where water comes out from the bottom of the fans. Grass tussocks and plants that were seen regularly in the tussock areas eventually became established in the open spaces between the shrubs (Cockayne and Foweraker, 1915). At 2001, the dominant species included *Discaria toumatou, Coprosma propinqua, Ozothamnun leptophylla*, and *Festuca novae-zealandiae.*

The incidence of *Leptospermum scorparium* thickets has changed since 1915 (Figure 2.3, Figure 2.4 and Figure 2.5). The species composition of this vegetation is similar to the *Leptospermum scoparium* composition in 1915 (Cockayne and Foweraker, 1915). Notable changes since 1915 have occurred in the river-terrace and debris scrub. Cockayne and Foweraker (1915) found river-terrace and debris scrub on the sides of the gullies cut by streams through a fan, and on the faces of the river terrace throughout the Waimakariri River basin, and on areas that comprise bare stony debris. This scrub community is a lot denser than in 1915 (Figure 2.3 and Figure2.5). The shrubs that grew in these areas in 1915 were mostly divaricating, such as *Pittosporum divaricatum*, *Discaria toumatou*, *Aristotelia fruticosa*, *Melicytus alpinus*, *Corokia cotoneaster*, *Coprosma propinqua*, *Coprosma parviflora*, and *Olearia virgata* (Cockayne and Foweraker, 1915). The ground plants included: *Cystopteris novae-zealandiae*, *Blechnum penna-marina*, *Polystichum vestitum*, *Lycopodium fastigiatum*, *Acaena sanuisorbae* var. *pusilla* and var. *pilosa*, *Epilobium pubens*, and *Epilobium chloraefolium* (Cockayne and Foweraker, 1915). The dominant species in this community in 2001 are *Hebe venustula, Dracophyllum* species, *Discaria toumatou, Celmisia spectablis*, and *Blechnum penna-marina.* Apart from the presence of *Discaria toumatou* and *Blechnum penna-marina*, this is quite different from 1915.

Cockayne and Foweraker (1915) referred to the low tussock grasslands as a product of burning and sheep grazing, resulting in the dominant species comprising *Festuca novae-zealandiae* and *Poa colensoi*. Other species that were also abundant include *Blechnum penna-marina, Lycopodium fastigiatum, Holcus lanatus, Poa pratensis, Carex breviculmis, Luzula* species, *Microtis uniflora, Muehlenbeckia axillaris, Rumex acetosella, Stellaria gracilenta, Scleranthus biflorus, Cerastium triviale, Ranunculus multiscapus, Acaena sanguisorbae* var. *pilosa, Geranium sessiliflorum* var. *glabrum, Viola cunninghamii, Pimelea prostrata, Hydrocotyle novae-zealandiae* var. *montana, Gaultheria depressa, Leucopogon fraseri, Plantago spathulata, Wahlenbergia albomarginata, Celmisia longifolia, Celmisia spectabilis, Brachycome sinclairii, Raoulia subsericia, Gnaphalium traversii, Ozothamnus leptophylla*, and *Hypochoeris radicata*. Although more species were present in 1915, the vegetation present in the grasslands in 2001 remains largely unchanged. Other comparable grassland areas in the South Island include Nigger Valley (Hustedt, 2002; Walker and Lee, 2002), Mackenzie basin and Ben Ohau Range (Conner, 1964), Hawdon Valley, North Hurunui Valley, Poulter Valley, Esk Valley and Cox Valley (Walker and Lee, 2002).

The forest community was poorly represented in 1915 (Cockayne and Foweraker, 1915) probably because of historical burning. The most abundant plant species in the forest remnants in 1915 was *Nothofagus solandri*. No other canopy species or sub-canopy species were found in this community, unlike most other forests, such as Mount Thomas forest, Canterbury (Wiser *et al.*, 1997). Other species that were also present in the forest in 1915 grew mainly close to the stream edges, including *Blechnum penna-marina, Blechnum novae-zelandiae, Polystichum vestitum, Lycopodium selago, Carex dissita, Corysanthes macrantha, Urtica incisa, Cardamine heterophylla* var., *Acaena sanguisorbae* var. *pusilla, Rubus subpauperatus, Rubus schmidelioides, Aristotelia fruticosa, Melicytus alpinus, Epilobium rotundifolium, Galium umbrosum, Coprosma parviflora, Hebe salicifolia, Hebe traversii*, and *Erechtites glabrescens*. The vegetation in the forest in 2001 is similar to that found in 1915, with *Nothofagus solandri* the most dominant species. Species found at the stream sides in 2001 but not in 1915, include mainly *Uncinia clavata, Hypolepis millefolium, Blechnum penna-marina, Polystichum vestitum, Blechnum fluviatile, Hypochoeris radicata*, and *Coprosma propinqua*.

The main difference between 2001 and 1914 is that the vegetation is now at a later stage of succession, with the forest, scrub and shrubland communities covering larger areas. If the fires that occurred at Cass (Table 2.4) had not occurred, and exotic animal grazing had reduced or stopped, then the vegetation change would have been more obvious. Disturbance history, topographical position, including microclimatic changes, and animals all affect regeneration.

3.4.1 Disturbance

Throughout New Zealand, fires are considered to be an important factor in the modification of montane vegetation (Primack, 1978). As described in Chapter 2, fires were frequently caused by Polynesians and Europeans. Polynesian fires appear to have occurred in the Cass area, reducing alpine and sub-alpine areas into barren communities (Burrows, 1977). Polynesian fires cleared forests and reduced snow-tussock grassland above the tree limit (Burrows, 1977). Europeans burned vegetation around Cass and specifically in the Cass study area during 1914 to 1947 (Molloy, 1977) for pastoral reasons. Other fires that have occurred since 1947 have been accidental. These factors are partly responsible for the existence of large areas of induced tussock grasslands, and regenerating shrublands and scrub communities in and around the Cass Research Area. Continued burning (intentional and accidental) has prevented areas of tussock grasslands from regenerating into other communities. Large scale fires, which have caused large scale deforestation, generally result in slow regeneration (Wiser, *et al.*, 1997). *Nothofagus solandri*, the main tree species Cass, is limited in terms of regeneration. This is mainly because the *Nothofagus* species is poorly adapted to fire, which kills most *Nothofagus* trees and seedlings (Druce, 1957). Regeneration from seed may also be limited as *Nothofagus* species do not produce seed every year. Even though seeds may survive the fire, they remain viable for only a short time (Wardle, 1984). *Nothofagus* species regeneration occurs primarily near the intact forest margin (Wardle, 1984), which is mainly due to poor seed dispersal, need for mycorrhiza, and to summer desiccation in open sites (D. Norton, pers. comm.).

Present day animal factors that influence vegetation patterns at Cass include sheep and rabbit grazing (possums, pigs and hares are also present but not in high numbers). Sheep and rabbits, in general, are known to avoid steep, south-facing slopes (which tend to be

moist) and prefer gentle, sunny gradients (Partridge *et al.*, 1991). This may also occur to some degree at Cass where grassland and shrubland communities occur. These plant communities receive more sunlight than those on the steeper slopes of Cass Hill and Sugarloaf. The presence of sheep and rabbits on the lower plant communities may slow the regeneration of plants, whereas the communities on the steeper, moister slopes are less affected by herbivores, thus increasing plant community regeneration. The undergrowth of the vegetation communities is affected by the presence of grazing animals (Cockayne and Foweraker, 1915). Sheep tend to shelter under the vegetation, preventing new growth from establishing. Disturbance is necessary for initial establishment of scrub vegetation (Primack, 1978), but it appears that sheep sheltering in the undergrowth at Cass may be smothering any plant establishment.

A study by McIntosh and Allen (1998) revealed an increase of plant cover, ground biomass and nutrients, and a greater root biomass relative to the grazed area. In Australia, generally, native species increase at low to moderate levels of grazing and decline with very low and very high grazing intensities (McIntyre and Lavorel, 1994; Tremont and McIntyre, 1994; Prober and Thiele, 1995). However, Primack (1978) found that over 16 years during which there was no grazing, there was no significant effect on soil nutrients and soil carbon, and this did not favour establishment of native flora. When grazing pressure intensifies, native species tend to be out-competed by exotic plants. Grazing does appear to increase exotic species establishment and displace native species in grassland communities (Treskonova, 1991; McIntosh and Allen, 1998). A study in Australia by (Yates *et al.*, 2000)) found that livestock grazing has an impact on vegetation structure, vegetation composition, soil surface condition, soil chemicals, physical and hydrological properties, and near ground and soil microclimate. Initially, animal excretion fertilises the soil, increasing nutrient availability to plants, but it has been found that in hilly and steep landscapes, increased nutrient availability is patchy (Sagger *et al.*, 1988; Rowarth *et al.*, 1992, both in McIntosh and Allen, 1998). Another effect of grazing on the soil in high country areas in the South Island is that without the replenishment of nutrients by fertiliser and oversowing, topsoil nutrient declines over time (McIntosh *et al.*, 1996), which may lead to the establishment of exotic species (Treskonova, 1991).

Whereas grazing at Cass appears to have increased shrub recruitment rates, browsing appears to limit species height (Primack, 1978). This is probably due to the shrub recruitment reducing the establishment of adventive grasses by competition. Grazing animals reduce the amount of plant tissue, thereby permitting light to reach the soil surface, and open the soil surface with their hooves, increasing the number of microsites appropriate for seed germination (Primack, 1978).

3.4.2 Topographical position

The results presented here (Table 3.4, Table 3.5, Figure 3.12, Figure 3.13, and Figure 3.15) indicate that environmental factors influence plant community distribution at Cass. Physiography and slope are the main measured factors that influence vegetation pattern, which has also influenced other vegetation communities in other areas (Williams, 1993; Wardle, 2001). Drainage largely determines whether plant communities survive on dry land or wet land, which has been found in other studies in New Zealand (Smith and Lee, 1984; Duncan and Norton, 1990; Partridge *et al.*, 1991; Walker *et al.*, 1995). Swamps differ from dry land communities because of water drainage. Differences in steepness between slopes (which are influenced by physiography: i.e. hill face, terrace, and gully) appear to influence the density of plants larger than grasses and sedges. Communities on steeper slopes tend to have more shrub and/or tree species than those on the lower slopes in the Cass study area. This pattern is probably also influenced by climate and grazing.

Microclimatic effects are present at the Cass study area and are caused by the topography and surface cover of the surrounding landscape (Greenland, 1977), and also from livestock grazing (Yates, *et al.*, 2000). Humidity, temperature and wind affect these physiographical features, with gullies providing shelter from wind. Gullies also may act as heat sinks, resulting in higher humidity in the gullies than on the terraces and hill faces. These different microclimates influence the vegetation communities in and around Cass.

3.4.3 Vegetation structure

Swamp and forest are the oldest and possibly the least dynamic vegetation communities present at Cass as they appear to be in the later stages of succession. Both of these

communities have higher dominance indices and lower diversity indices (although the Grassland community has a lower DI than the forest community) (Table 3.3). The streamside and slips contain higher plant diversity than other parts of the forest, which is predominantly *Nothofagus solandri*. The lack of plant regeneration in large areas of the forest community is probably largely caused by sheep. The smell of sheep is strong in some areas of the forest, possibly due to sheep sheltering from climatic factors, as well as using the forest as a passageway to Sugarloaf Saddle and the Waimakariri River side, and back again (pers. obs.). Due to this sheep activity, new vegetation is prevented from establishing in large numbers. This indicates that the swamp and forest (excluding stream sides and slips) are less dynamic communities than the other plant communities present at Cass. The Grassland community appears to be the next least dynamic community present at Cass. Historic fires and grazing probably influence species richness, dominance indices, and diversity indices, making them lower than those of the shrubland, scrub 1, and scrub 2 communities. Grazing probably prevents regeneration of shrub species.

The shrubland community appears to be more dynamic than the swamp, forest, and grassland communities in terms of regeneration. Species richness and diversity indices are lower than those of the scrub communities, and the dominance indices are higher. This is possibly caused by fewer grazing by sheep and rabbits, as this plant community is on higher slopes than the grassland community. Higher slopes tend to receive less sunlight, and sheep and rabbits prefer sunnier areas. The two scrub communities have similar species richness, dominance and diversity indices, which indicates that these communities are very similar in terms of regeneration. Less grazing by sheep and rabbits probably hastens community regeneration in these scrub communities.

Another pattern that is seen in the Cass area is that these plant communities that are in the earlier stages of regeneration tend to have more exotic plant species within the community. In this study the grassland community is in the earlier stages of regeneration, due to sheep and rabbit grazing, as well as recent fires. Sixty-five percent of plant species are exotic in the grassland community. Shrubland has the next highest number of exotic species, followed by the shrubland community (30%), scrub 1 community (24%), scrub 2 community (16%), forest community (9%), and finally the swamp community with no

exotic species. This pattern suggests in the later stages of succession, the number of exotic species surviving is fewer.

3.5 Summary

Forest and swamp communities appear to be in the later stages of succession at Cass. Grassland, shrubland, scrub 1, and scrub 2 appear to be at different stages of regeneration, with the Grassland community at an earlier stage than the other plant communities. The main factors that influence these different stages in regeneration and succession are probably disturbances due to fires and grazing, as well as topographical factors. From these conclusions, it can be said that vegetation communities at Cass study area form a dynamic mosaic responding to past and present disturbances.

This vegetation pattern and understanding of the factors that influence it provide a useful framework within which to study possum resource selection at the Cass study area.

Chapter 4 Possum movements

4.1 Introduction

The Cass study area is spatially heterogeneous. This heterogeneity may have important ecological implications for animals living there, as spatial heterogeneity can influence animal movement patterns (Johnson *et al.*, 1992), and is likely to affect possum distribution and foraging behaviours at Cass.

Possum movement patterns are commonly influenced by seasonal variation of key resources, resulting in seasonal concentrations of animals in specific locales (Jolly, 1976). Information on possum home range and movements will increase the general understanding of possums' ability to adapt to different habitats. Chapter 3 describes habitats that exist at the Cass study area. With knowledge of the vegetation structure, in conjunction with knowledge of possum movement patterns and home range, inferences can be made about the quantity and quality of available and preferred possum habitats. Furthermore, an understanding can be gained of how possums utilise their surrounding landscape.

Possum home range in this study is defined by the area a possum's den is in, it feeds in, and it breeds in. Studies of possum home ranges have found that they tend to be larger in habitats where there is a low possum density, or if possums have access to farmland (Cowan and Clout, 2000). Possum home range sizes in Australia are similar to home range sizes in New Zealand, although it appears that in New Zealand home ranges are more variable (some very small home range sizes to very large home range sizes).

The first objective of this chapter is to determine whether male possums in the Cass study area have a larger home range size and home range length than female possums. Previous studies have found that male possums tend to have larger home ranges, and home range lengths (length of the longest part of the home range) than females (Dunnet, 1964; Jolly, 1976; Clout, 1977; Ward, 1978; How, 1981; Clout and Gaze, 1984; Green, 1984; Green and Coleman, 1986b; Paterson *et al.*, 1995; Stratham and Stratham, 1997). The reasons why male home ranges are larger than female home ranges is unknown, but are probably related to males travelling over larger distances in search of mates. Another reason maybe that female's have to care for their young for up to 240 days, until their offspring are able

to care for themselves (Fletcher and Selwood, 2000).

The second objective of this chapter is to determine whether possums at Cass show seasonal variation in their home range. Most possum home range studies have found that possums exhibit seasonal variation in their home ranges (Jolly, 1976; Ward, 1978; Thomas *et al.*, 1984; Brockie *et al.*, 1987), due to seasonally available food resources such as fruit, fungi, flowers, seeds and new leaves, (Cowan and Clout, 2000).

The third objective of this chapter is to determine whether possums at Cass share the same den sites. Generally, possums have between five and ten den sites within their home ranges, and possums are known to share dens. If there are adequate dens for each possum, then possums will not stay in the same den as another possum, but they will occupy the same den at different times (Day *et al.*, 2000). If there is a high density of possums in the area, it is more likely that they will share dens simultaneously with other possums. Sharing generally occurs between mother and their offspring, or between a breeding pair (Day, *et al.*, 2000).

The fourth objective of this chapter is to determine whether possum home ranges overlap at Cass. Possum home ranges generally overlap with each other between sexes and within sexes (Crawley, 1973; Green, 1984; Paterson, *et al.*, 1995). The amount of possum home range overlap is influenced largely by social interactions and density. It has been found that more dominant individuals extensively overlap home ranges with lower ranking possums (Clout, 1977). Young females tend to establish home ranges close to their mothers, thus increasing the chances of home range overlap (Clout and Efford, 1984). The general trend for young males is that their home range tends to gradually shift further away from their mother (Cowan and Clout, 2000). Competition for resources will increase if possums forage and den in areas that are within another individual's core home area. Low densities of possums in an area enable them to move around more freely without having to come in to contact with other individuals, and therefore they are likely to have less contact with another possum's core home range area. This reduces the amount of social interaction (competition) that each possum will experience.

The fifth objective of this study is to determine whether possums in the Cass study area exhibit a bimodal ranging behaviour. Bimodal possum home range behaviour occurs when

possums den in one area and then feed a significant distance away (Cowan and Clout, 2000). This type of ranging behaviour has been found for possums in other studies (Cowan and Clout, 2000).

The hypotheses of this chapter are:

1) The home range size and home range length of male possums will be larger than females in the Cass study area.
2) Possum home ranges will exhibit a seasonal variation in the Cass study area.
3) Possums in the Cass study area will not share the same den site with other possums at the same time.
4) Possum home range overlap in the Cass study area will occur for less than 50% of the possums studied.
5) Possums will exhibit a bimodal ranging behaviour in the Cass study area.

4.2 Methods

4.2.1 Radio transmitters

Cage traps (Figure 4.1) were originally used to trap possums in the Cass study area to be fitted with radio-transmitter collars, but due to the instability of the cage traps, soft-leghold (victor) traps were used for most of the trapping. The cage traps were not convenient to use because the possums moved rigorously inside the cage, often causing it to collapse. The cage traps were baited with apple and cinnamon and the leghold traps were baited with flour and raspberry essence. Ethics approval was obtained from the University of Canterbury Animal Ethics Committee for trapping and collaring the possums. Possums were trapped alongside forest remnant margins, forest remnant streamsides, and close to the railway tracks (along the fence line) and next to the Geography Department hut (Figure 4.3). Traps were checked early each morning. Traps were put in areas where possum sign was present, and in areas where leghold traps were easy to set up (i.e. against trees and fences). Possum sign was not seen in the swamp or grassland communities. Few possums were trapped in the shrubland and scrub communities, although possum sign was present, as it was difficult to set up leghold traps. Stakes were originally used in the shrubland and scrub communities but were not very efficient. The stakes provided for setting up the leghold traps were approximately 40 cm long, square, with a width of approximately 4 cm. These stakes proved hard to place firmly as the ground was quite hard, so placing the stake

deep in the ground was very difficult. Also attaching the leghold trap to the stake was difficult. Nailing the leghold trap to the stake with a staple quite often split the stake, therefore rendering the stake useless.

Figure 4.1 Cage trap in a forest remnant in the Cass study area. The cage trap has a black possum sleeping at the closed end of the trap (photo: E. de Zwart, 2000).

4.2.2 Radio-telemetry

The radio-tracking equipment used for this study is from Sirtrack Limited (1999). Radio-transmitter collars, working on a frequency of 160 MHz band and weighing 33 grams (1.3 % of average possum body weight), were fitted to the possums. The radio-transmitter signals were tracked using Telonics TR-4 receivers with Sirtrack's hand-held 3-element yagi antennas (Sirtrack, 1999). The 12 radio-collared possums were radio-tracked six times over 10 months, starting in May 2000, with subsequent measurements in July 2000, September 2000, November 2000, January 2001, and finishing in March 2001. Each radio-tracking session was undertaken for a period of three consecutive nights. If it rained on one of the consecutive nights, then that night was missed and replaced by another radio-tracking night when the weather cleared. Radio-tracking could not be carried out in wet weather as the radio-telemetry receivers were not waterproof, and because possums behave

differently in wet weather (Ward, 1978), and it was desirable that possum home range data collection was comparable throughout the study. During each night of radio tracking, five fixes were recorded: early afternoon (first den site), 9pm, midnight, 3am, and early afternoon (last den site). These times were used as they provided sufficient time to locate and record all the sample possum's locations accurately within the study site. The animals were always located in the same order so as to keep the recording consistent throughout each night during the sampling period.

Possum locations were recorded by walking to within 50-60 m of the individual possum then identifying the correct grid cell in which they occurred (Figure 4.2). Possums could not be recorded at closer distances as this would have disturbed them, and it was thought that disturbance of this sort may result in the possums moving away from that particular area, thus biasing the results. If the night was clear, then the headlamps were not used, as visibility was sufficient without them. Not using the headlamps and walking quietly through the study area were also precautions against the possibility of changing the possum ranging behaviour during the recording sessions.

The Cass study area was divided into a grid system (Figure 4.2) consisting of 100 m × 100 m grid cells. Radio tracking fixes were located on the grid system. In grids that consisted of forest-scrub and gully-shrubland and other physiographical types, it was possible to differentiate between vegetation types indicated during data collection for individual possum fixes. For this Chapter, these results were used only for the den site location areas. Chapter 6 used the vegetation community locations for habitat selection analysis.

Most radio-telemetry studies calculate the home range of the animals by using triangulation (Jike *et al.*, 1988; Parker *et al.*, 1996; Edwards *et al.*, 2001; Miller *et al.*, 2001). The reason why this study used grid cells instead of triangulation is because a pilot study was done at Cass which resulted in the triangulation errors being relatively large. Regularly the grid cells had more than one vegetation community present, consequently due to the landscape and the small study area it was possible to differentiate between the different vegetation communities, which was recorded for each possum. This extra information was used in determining possum habitat selection in Chapter 6.

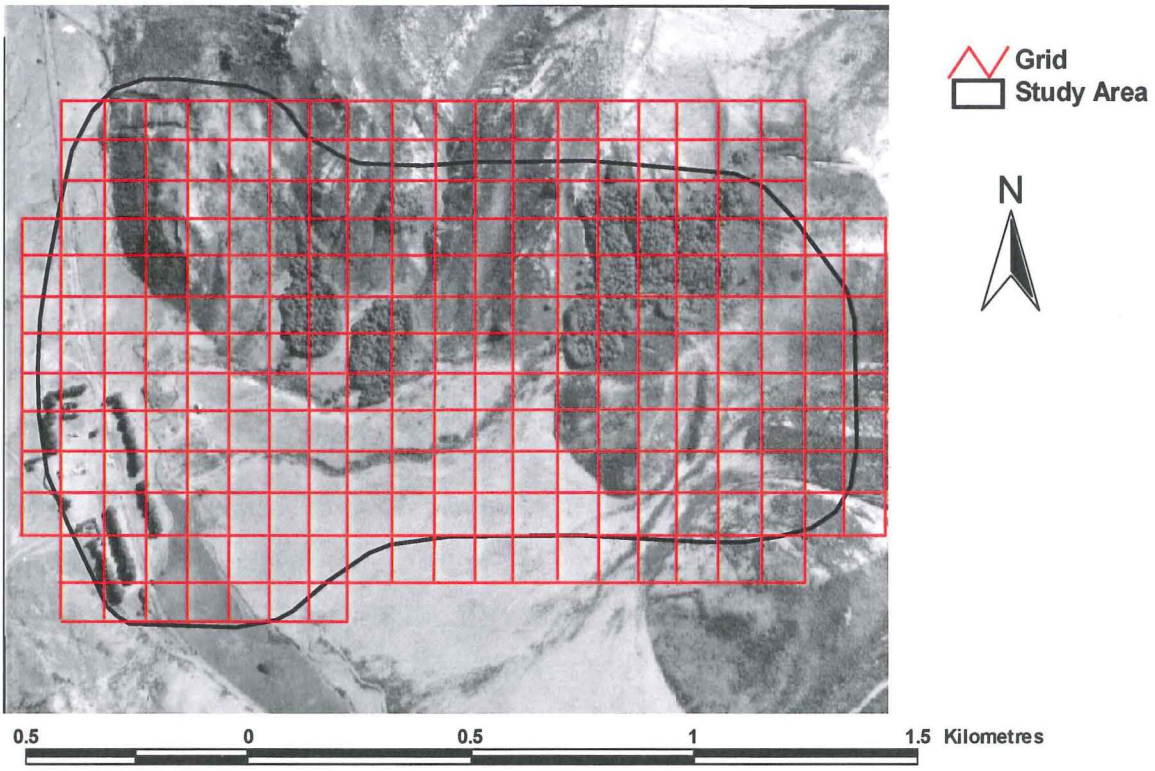

Figure 4.2 100 m × 100 m grid system used for locating possums during the radio-telemetry data collection at Cass study area for a period from May 2000 to March 2001.

When using radio-tracking equipment, it is assumed that animal behaviour, reproduction and survival are not affected by the radio transmitters (Burger *et al.*, 1991).

4.2.3 Geographical Information Systems (GIS)

Using ArcView™ GIS, the grid was added into the programme as a theme; next the possum locations were placed into the view as another theme. The individual possums were labelled differently within the same theme table, as well as the different times and different months, that the data were collected. With all the data placed in GIS the animal movements programme (Hooge *et al.*, 1999) calculated the MCP and Kernel home range estimations. From these calculations, GIS diagrams from each possum were overlayed on an aerial photograph of the study area. This enabled possum bimodal behaviour and possum overlapping ranging behaviour to be determined.

4.2.4 Home range

The possum home range area was analysed by using two techniques: minimum convex polygon (MCP) (Harris *et al.*, 1990), and the kernel method (Worton, 1989) . The kernel method can provide a more accurate home range estimate than the MCP home range estimates (Worton, 1995). However, the Kernel home range estimator does not include areas that are seldom used or not used at all by the animal (95% home range contours were calculated (Seaman *et al.*, 1998)), whereas the MCP home range estimator incorporates the whole area, which therefore overestimates the true home range area (Harris, *et al.*, 1990). The Kernel method produces a density estimation that may be interpreted as an Utilisation Distribution (UD) (van Winkle, 1975), which provides 3-dimensional estimates of home ranges, and calculates 95% of the estimated UD (Seaman, *et al.*, 1998). The third dimension corresponds to the extent of time an animal spends in any specified area of its home range (Seaman *et al.*, 1999). The MCP is one of the earliest and more simplistic techniques used for home range estimations and is one of the most frequently used home range estimators (Harris, *et al.*, 1990), therefore enabling comparisons with other studies. The MCP home range estimator is also more robust than most other home range estimators are when the number of sampling fixes is low (Harris, *et al.*, 1990). Inclusion of the MCP home range estimator is the only technique that is strictly comparable between studies, therefore making it a valuable home range estimator in conjunction with the Kernel home range estimator (Harris, *et al.*, 1990).

All home range estimators are subject to sampling errors, but these errors reduce as sample size increases (Seaman, *et al.*, 1999). The MCP method produces a non-statistical home range estimate, which is not affected by dependent data (Meek and Saunders, 2000). Dependant data causes autocorrelation (see 4.2.9, Associated errors with analysis techniques). An MCP is estimated by using a space-use index provided throughout data collected from the study.

The inclusion of the MCP as one of two methods of range calculation is therefore valuable in that:

1) It is the only home range technique that is strictly comparable with other studies;
2) The MCP is one of only a few methods that can give comparable results between grid trapping and telemetry data (Jones, 1983), and;
3) It is a more robust home range technique than most other techniques used in home

range studies.

The main disadvantages of the MCP method are that:

1) The intensity of the range use is not indicated;
2) Large areas are included in the home range, even areas that were not visited by the animal that is studied, more so than other home range techniques, and;
3) The home range boundary includes all fixes, including areas that were only occasionally used by the animal studied.

The Kernel method of home range estimation produces a likelihood density estimate of the home range distribution based on a sample of points (Seaman, *et al.*, 1998). Home range and utilisation distribution (UD) is estimated (Worton, 1989).

The main advantages of the Kernel method are that:

1) It has the potential to estimate accurate home ranges of any shape using nonparametric data, if the appropriate level of smoothing is designated;
2) It can produce a density estimate directly, and;
3) The home range is not estimated by grid size or placement (Seaman, *et al.*, 1998).

The main disadvantages of the Kernel method are that:

1) At least 30 observations per animal are needed to be statistically viable. In terms of this study, the Kernel method can only be used for the data collected over the whole year.

Estimation of the home ranges from the MCP and Kernel methods enabled statistical analysis comparing female possum and male possum home range sizes and lengths, by using a Mann-Whitney Test (Zar, 1999). The Mann-Whitney Test is a nonparametric procedure that does not use actual data, but instead ranks data from either the highest to lowest or lowest to highest. In this analysis, ranking is from highest to lowest measurement. The highest rank is given one and the lowest rank is given 11. Females were assigned n_1 and males assigned n_2. The ranks are added for each sex, with R_1 assigned to females and R_2 assigned to males. From this, the Mann-Whitney statistic is calculated by:

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

with U being the Mann-Whitney statistic for female possum home range size. The male possum home range statistic (U') is calculated by:

$$U' = n_1 n_2 - U$$

If U or U' is greater than or as great as $U_{0.05\,(2),\,n1,\,n2,}$ then the null hypothesis is accepted. In this case, the null hypothesis is that female and male possums at Cass have statistically similar home range sizes from May 2000 through to March 2001.

4.2.5 Core range

The core range is the area where each individual possum spends 50% of its time within its home range period. The Kernel method was used to explain annual measurement for possum core range areas. The core home range is calculated by estimating 50% of the estimated UD (Seaman, *et al.*, 1998). Unfortunately, in this possum study, not every radio-tracking session (two monthly) can be tested for, as mentioned before, the Kernel method requires a minimum of 30 observations per animal for it to be relatively accurate. Each radio tracking period comprised 12 observations per animal. Therefore, two-monthly differences between sexual and seasonal core home range areas cannot be determined using the Kernel home range estimator, but the annual gender core home range areas can be determined. The MCP home range estimator was used to test possum differences between seasons.

Core areas of home range can be determined by using a grid cell method analysis, such as in this study. Home range core areas are defined as the grid cells that contained a significantly greater proportion of fixes over all other grid cells (Harris, *et al.*, 1990). The defined core areas frequently involve a large proportion of total home range, thus producing a 'coarse-grained' pattern. The importance of defining core areas, in terms of possum control, is that these are areas possums tend to frequent more often, thus resulting in a higher chance of possums being trapped/poisoned, therefore increasing efficiency in possum control.

4.2.6 Seasonal variation

The Wilcoxon Paired-Sample Test (Zar, 1999) was used for statistically analysing seasonal difference in possum home ranges at Cass. Minimum convex polygon estimated home range sizes.

The Wilcoxon Paired-Sample Test is used on nonparametric data, which is a suitable test for radio-telemetry data. This procedure involves calculating differences between seasonal home ranges, which are then ranked for the whole data set from the lowest value to the highest value, similar to the Mann-Whitney Test. The ranks are then either assigned T_+ (positive ranks) or T- (negative ranks), and then summed. The null hypothesis is rejected if T+ or T- is less than or equal to the critical value ($T_{0.05(2),n}$). The null hypothesis for this study is that there is no seasonal difference in possum home range size at Cass.

4.2.7 Range length

Individual possum home range length was calculated in Geographical Information Systems, ArcView™ using the distance function. The home range length gives an estimation of the maximum distance possums move in their home range, which in terms of poisoning operations gives a maximum distance that possums may move to traps, bait stations, and poison lines (Cowan and Clout, 2000).

4.2.8 Den sites

The den site area for each possum was calculated in ArcView™ GIS, using MCP estimates in the animal movements programme. The kernel home range estimate calculation was not used, as mentioned before this estimation method requires a minimum of 30 radio-location points. Estimating the den site area for each possums results in a maximum of 24 radio-locations throughout the year.

4.2.9 Associated errors with analysis techniques

Autocorrelation occurs in telemetry studies, which can underestimate home range size (Swihart and Slade, 1985), flaw range utilization descriptions (Rooney *et al.*, 1998), and cause negatively biased estimates of home range (Otis and White, 1999). Autocorrelation

occurs whereby the location of the animal studied at time $t + 1$ is not independent of its location at time t (Rooney, *et al.*, 1998). The ability to predict an animal's location will be high if autocorrelation is high. Therefore in terms of radio-tracking, if the data is highly autocorrelated then the resulting description of the animals home range size may be underestimated (Rooney, *et al.*, 1998). To overcome autocorrelation it is suggested taking successive fixes at the times it takes the study animal to reach any point within its home range, or the shortest time taken for the study animal to cross its entire range (Rooney, *et al.*, 1998). Generally, this requires a pilot study on the animals movements in order to estimate the amount of time it takes the animal to cross their home range. Fortunately, some possum studies have researched this, and have resulted in approximate descriptions of what possum movements are through the night (Ward, 1978; MacLennan, 1984; Paterson, *et al.*, 1995), therefore, inferences were made from these about how many times were sufficient in recording possum movement. In home range studies, the main objective is to acquire information on the study animal's home range, including the boundary and area traversed during the period of interest. From this information, inferences can then be properly constrained to the specified frame of the study (Otis and White, 1999). If the subsample is accumulated with a sampling design that assures unbiased temporal coverage of the animal's movements during the study phase, then the concern of autocorrelation is of no consequence (Otis and White, 1999).

Misinterpretation of habitat use will occur if radio-telemetry error associated with point location data is not considered when evaluating habitat use (White and Garrott, 1986; Saltz, 1994). In this study, the grid size may be too large in some respects. Some grid cells encompass more than one vegetation type, but due to the grid size and the home range estimation techniques, the possums may in actuality be registered in a different vegetation type. Within GIS, possum location points were placed in the middle of each cell. This then allows the program to analysis the data consistently. The programs consider each location point to be classified as the area (grid cell) that they occurred in, therefore the estimates are developed for the proportion of time each animal spends in the different areas (Kernohan *et al.*, 1998).

Another possible error that may result from the 1×1 ha size grid cell is that some possums may not have large home ranges, therefore the fixed-density estimate of the observation points may not show a complete home range area (unconnected home range) of the

possum. If this results, then the smoothing function for the adaptive Kernel method must be used (Seaman, *et al.*, 1998), which allows the home ranges to be smoothed together. However, this results in larger home ranges, although this will reduce the level of unconnected home ranges. The larger the smoothing factor, the larger the home range area of the possum. The error that is associated with the smoothing factor is that other areas (that the possum did not encounter) become part of the possum's home range. This must be taken into account when analysing home range data.

4.3 Results

Financial constraints only allowed for 12 possums to be captured and radio-collared. Figure 4.3 shows the locations where the 12, six females and six males, possums were caught for this study (Table 4.1). Eight possums survived the radio-telemetry period at the Cass study area. This means that these eight possums can only be used for estimating annual home range sizes. Possum 26 was found in Reservoir Bush, and died of natural causes between the initial capture and the first radio-telemetry session. Possum 40 died of natural causes between the July and September radio-tracking period. Possums 10 and 32 died between the September and November radio-telemetry periods. Possum 10 died of natural causes and Possum 32 was shot close to the Cass train station.

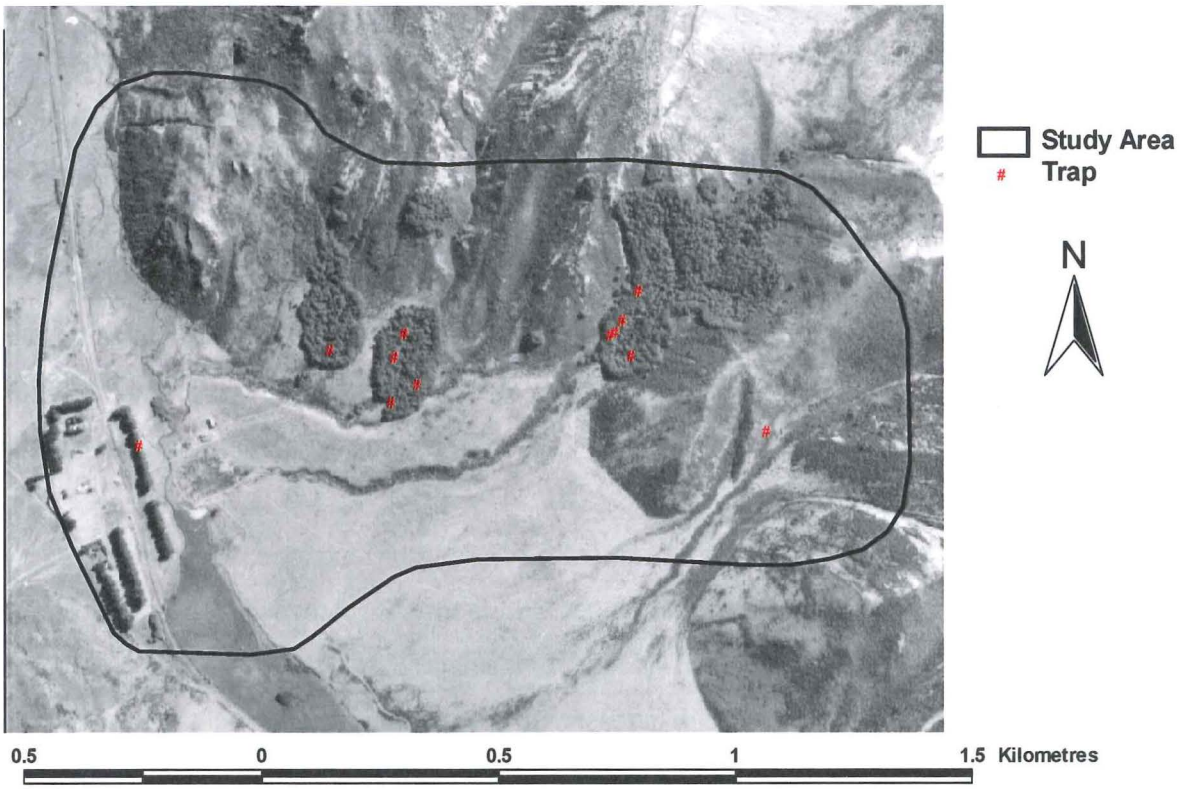

Figure 4.3 Aerial photo of the Cass study area showing where the 12 radio-collared possums were caught.

Table 4.1 Gender, weight (kilograms), and body length including the tail (centimetres) of the individual possums (radio-collared) used in this study. * demarcates possums that died during the sampling period.

	Possum	Sex	Weight	Body length
Female	2	Female	3.7	83.0
	10 *	Female	3.1	80.0
	12	Female	3.2	82.0
	16	Female	3.0	77.0
	18	Female	2.6	72.0
	26 *	Female	2.7	79.0
	Average		3.1	78.8
Male	4	Male	2.3	74.0
	6	Male	1.9	63.0
	8	Male	3.0	73.0
	32 *	Male	3.6	84.0
	38	Male	1.8	66.0
	40 *	Male	3.3	82.0
	Average		2.7	73.7

4.3.1 Home range and range length variation between sexes

Results for Possums 10 and 32 give an indication of possums living exclusively in scrub communities. All the other possums utilised mainly the scrub and forest communities. Possums 2, 4, 6, 8, 10, 16, 18, and 40 were in need of the smoothing function with the use of the Kernel home range estimation. Possum 10, 32 and 40 were included in the results as their home range movements were relatively large for the short time that they were present in this study. Possum 12 required a smoothing factor of 40. Possums 6, 10, 16, and 18, required a smoothing factor of 50. Possum 4 required a smoothing factor of 60. Possums 2, 8, and 40 required a smoothing factor of 70. A large smoothing factor indicates a larger home range area of the possum.

The home range sizes of possums ranged from 5 - 24 ha, with an average of 11.3 ha for females and 17.4 ha for males (Kernel home range) and from 4 - 20 ha (MCP home range), with an average of 10.2 ha for females and 11.9 ha for males (Table 4.2). Possum home range of females and males, pooled over all seasons, differed between the two home range estimator methods, with the MCP generally having a smaller home range. The mean home ranges of possums at Cass are not significantly different. Both home range estimators resulted in the Mann-Whitney statistic (U) being less than $U\alpha_{(2),\, n1,\, n2}$ therefore female and male home range areas are statistically similar in the Cass study area (Table 4.3).

Possum core range areas at Cass span from 1 ha to 5 ha, with and average of 2 ha for females and an average of 2.7 ha for males, using the Kernel home range estimates (Table 4.2).

Possums exhibit a variety of home range lengths varying from 348 - 1023 m for the Kernel home range length estimates, and from 288 m to 873 m for the MCP home range length estimates (Table 4.2). There is no statistical difference between female and male possum home range length in the Cass study area. The home range lengths between females and males showed a similar pattern to the Mann-Whitney results for differences between possum home range area, with both MCP home range estimations and Kernel home range estimations the Mann-Whitney statistic being larger than the U value (Table 4.3).

Table 4.2 Possum annual home range area (ha), home range length (m) of Minimum Convex Polygon home range (MCP) and kernel home range (KHR 95) estimations, and the core home range (KHR 50) at the Cass study area. * indicates possum death.

	Possum	KHR 50	Range	KHR 95	Range	MCP	Range
Female	2	2.9	192.9	19.7	931.2	19.7	800.6
Female	10 *	1.7	204.7	8.7	418.1	11.5	287.9
Female	12	1.1	172.6	5.4	348.0	4.0	365.4
Female	16	1.7	137.9	11.2	546.0	8.4	602.3
Female	18	2.9	254.5	11.4	438.3	7.4	422.5
	Average	2.0 ± 0.4	192.5 ± 19.2	11.3 ± 2.4	536.3 ± 103.7	10.2 ± 2.7	495.7 ± 92.1
Male	4	2.3	211.5	8.1	408.5	5.3	523.2
Male	6	2.1	153.2	12.3	718.3	11.1	872.7
Male	8	2.9	241.2	19.9	790.0	10.9	662.6
Male	32 *	2.6	206.7	18.6	738.6	13.6	621.3
Male	38	2.8	192.4	24.3	1022.5	19.0	868.2
Male	40 *	3.5	177.7	21.5	873.6	11.7	733.3
	Average	2.7 ± 0.2	197.1 ± 12.3	17.4 ± 2.5	758.6 ± 83.4	11.9 ± 1.8	713.5 ± 56.7

Table 4.3 Mann-Whitney test showing Minimum Convex Polygon home range (MCP) and Kernel home range (KHR) and home range length calculations.

Home range	U	U'	$U_{0.05(2),\,6,5}$	Home range length	U	U'	$U_{0.05(2),\,6,5}$
MCP	11	19	27	MCP	13	17	27
KHR	24	6	27	KHR	5	25	27

As there is no statistical difference between female and male home range areas and home range lengths, all the possums will be combined when considering seasonal differences.

4.3.2 Seasonal home range variation

Minimum Convex Polygons were used to test the seasonal differences of possum home ranges. The results of the Wilcoxon paired sample-test show that there is no seasonal variation since the difference between the sums of ranks are greater than the critical values (Table 4.4). Table 4.5 shows that the variation in possum home ranges from May 2000 to March 2001 fluctuates between possums and seasons. Zero indicates that possums did not move out of one cell.

Table 4.4 Wilcoxon paired-sample test results showing home range area differences between radio-collared possums in the Cass study area, from May 2000 to March 2001, using Minimum Convex Polygon (MCP) estimated home range areas. T+ is the positive sums of ranks. T- is the negative sums of ranks. n is the sample size. If T+ or T- is less than the critical value, then there is a statistical significant difference.

Months	T+	T-	n	Critical value
May/July	50	16	11	10
May/September	46	9	10	8
May/November	21	15	8	3
May/January	28	8	8	3
May/March	25	11	8	3
July/September	40	15	10	8
July/November	10	26	8	3
July/January	24	12	8	3
July/March	24	12	8	3
September/November	6	30	8	3
September/January	28	8	8	3
September/March	17	19	8	3
November/January	30	6	8	3
November/March	31	5	8	3
January/March	11	25	8	3

Table 4.5 The absolute seasonal home ranges for Minimum Convex Polygon home range estimations (ha), for each possum, from May 2000 to March 2001. – indicates the death of possum.

Possum	May-00	Jul-00	Sep-00	Nov-00	Jan-01	Mar-01
2	1.0	1.1	1.1	5.7	8.3	0.0
4	2.4	1.9	0.6	1.2	0.0	0.6
6	5.8	0.5	6.0	4.5	2.0	1.4
8	2.6	3.4	1.5	2.4	0.1	2.6
12	1.6	1.0	1.0	0.6	0.5	2.0
16	4.2	2.2	1.2	3.7	0.7	0.9
18	3.9	2.4	1.9	2.4	1.2	1.5
38	3.6	7.0	3.3	11.8	2.3	8.2
10	0.1	0.0	1.0	-	-	-
32	8.2	7.0	4.1	-	-	-
40	6.1	1.5	-	-	-	-

4.3.3 Home range overlap

Table 4.6 shows nine possums with some degree of home range overlap with another possum, include: Possums 2, 4, 6, 8, 12, 16, 18, 38, and 40 (Figure 4.4 to Figure 4.13). There does not appear to be a statistical difference between females and males overlapping home range areas, as five possums that were exhibiting home range overlap were male and four were females. Some possums also share core areas with other possums that were studied (50% of radio-telemetry fixes). These overlaps occurred between female-female,

female-male, and male-male possums (Table 4.6).

4.3.4 Bimodal home range

Six of the possums (2, 6, 16, 32, 38, and 40), female and male, studied at Cass exhibit a bimodal home range (Figure 4.5, Figure 4.7, Figure 4.9, Figure 4.11, and Figure 4.13). Possums showing this bimodal ranging behaviour generally have a large home range area.

Overlapping of home ranges occurred between all possums except for Possums 10 and 32 (Table 4.6). Overlapping of core home ranges occurred between Possums 4, 6, 8, 16, and 40, as well as between Possums 2, 12, 18, and 38 (Table 4.6).

Table 4.6 Table showing home range and core home range overlap. The first five possums are female; the latter six possums are male. +, indicates overlap.

		Core Home Range									
	Possum	2	10*	12	16	18	4	6	8	32*	38	40*
Home range	2			+		+					+	
	10*											
	12	+				+					+	
	16	+		+			+	+	+			+
	18	+		+	+						+	
	4	+		+	+	+		+	+			+
	6	+		+	+	+	+		+			+
	8	+		+	+	+	+	+				+
	32*											
	38	+		+	+	+	+	+	+			
	40*	+		+	+	+	+	+	+		+	

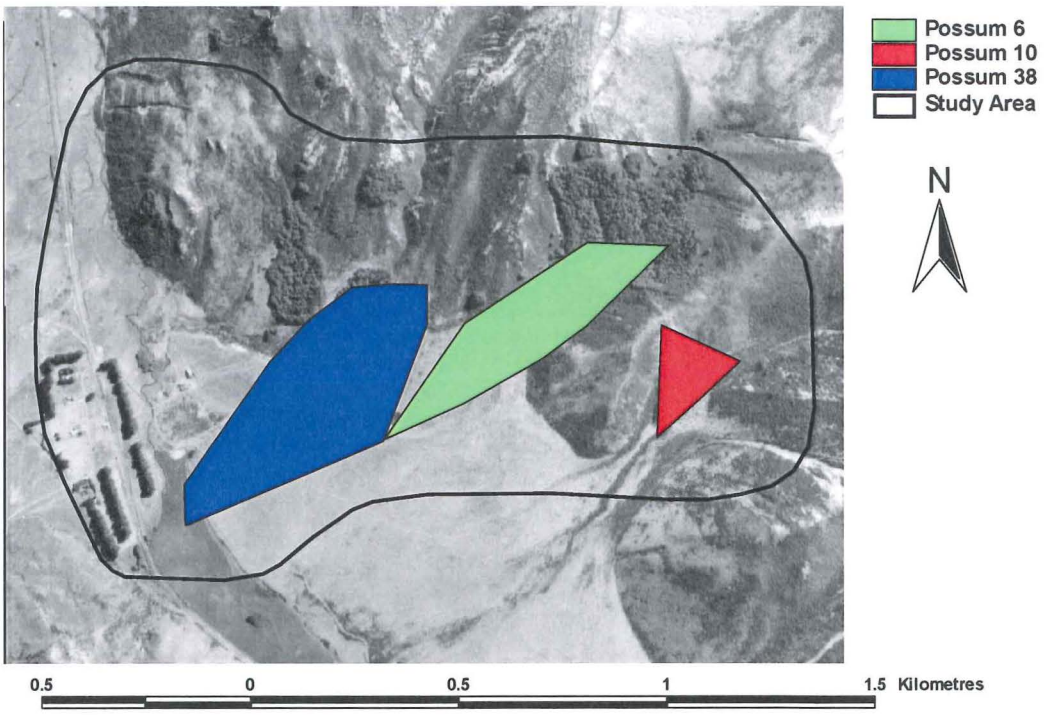

Figure 4.4 Minimum Convex Polygon annual home range estimations of Possums 6, 10, and 38 in the Cass study area.

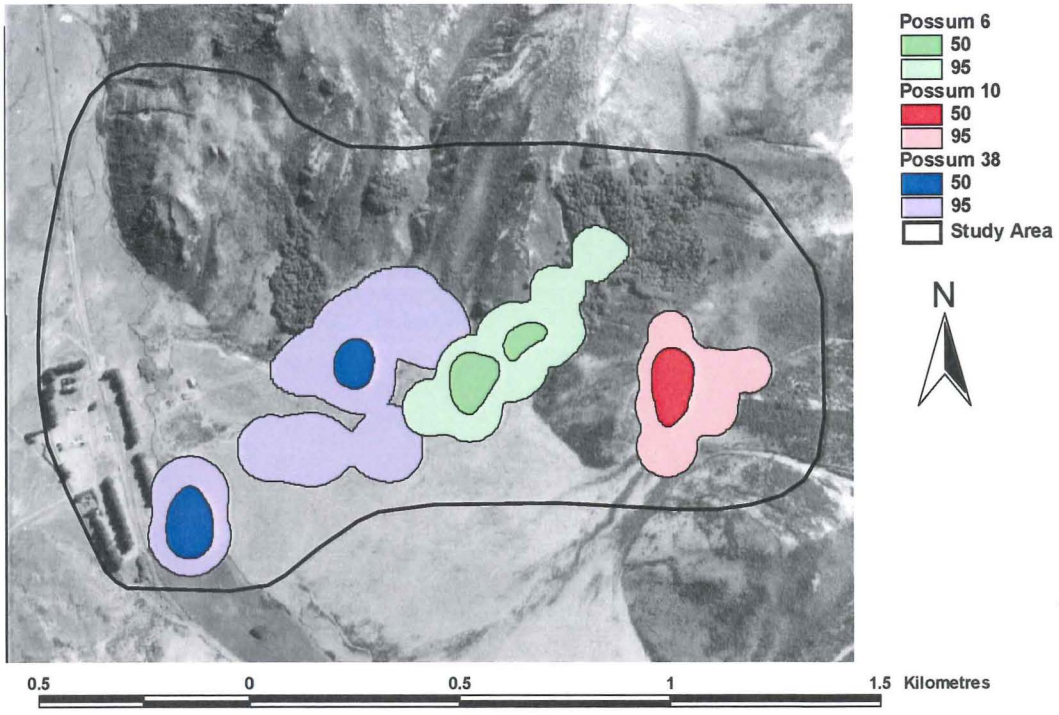

Figure 4.5 Kernel annual home range estimations of Possums 6, 10, and 38 in the Cass study area.

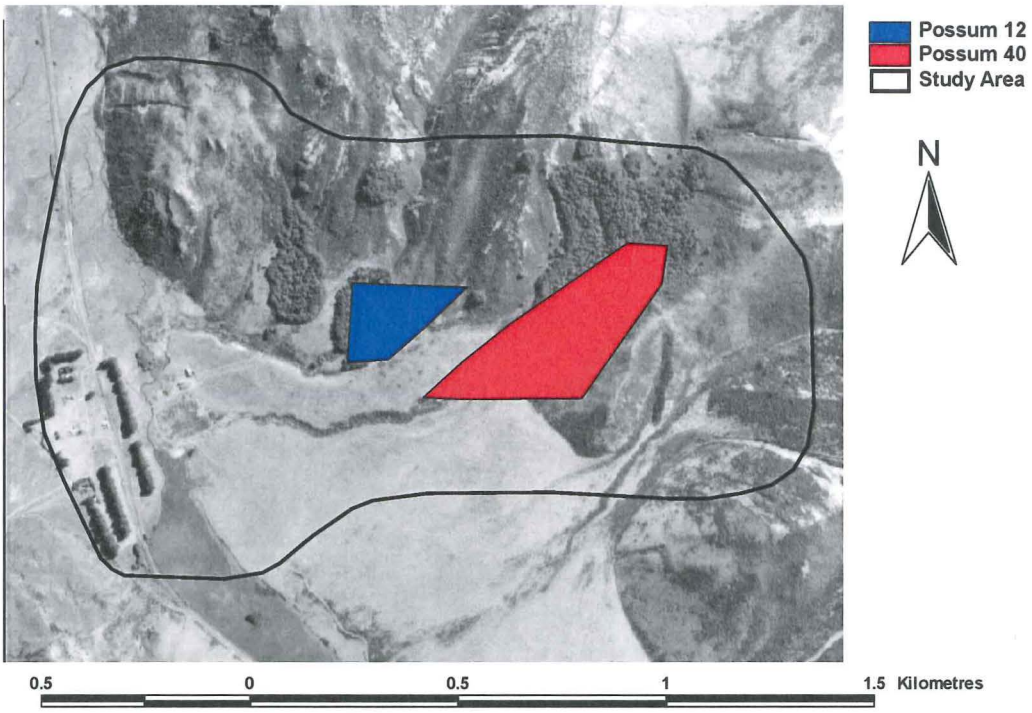

Figure 4.6 Minimum Convex Polygon annual home range estimations of Possums 12, and 40 in the Cass study area.

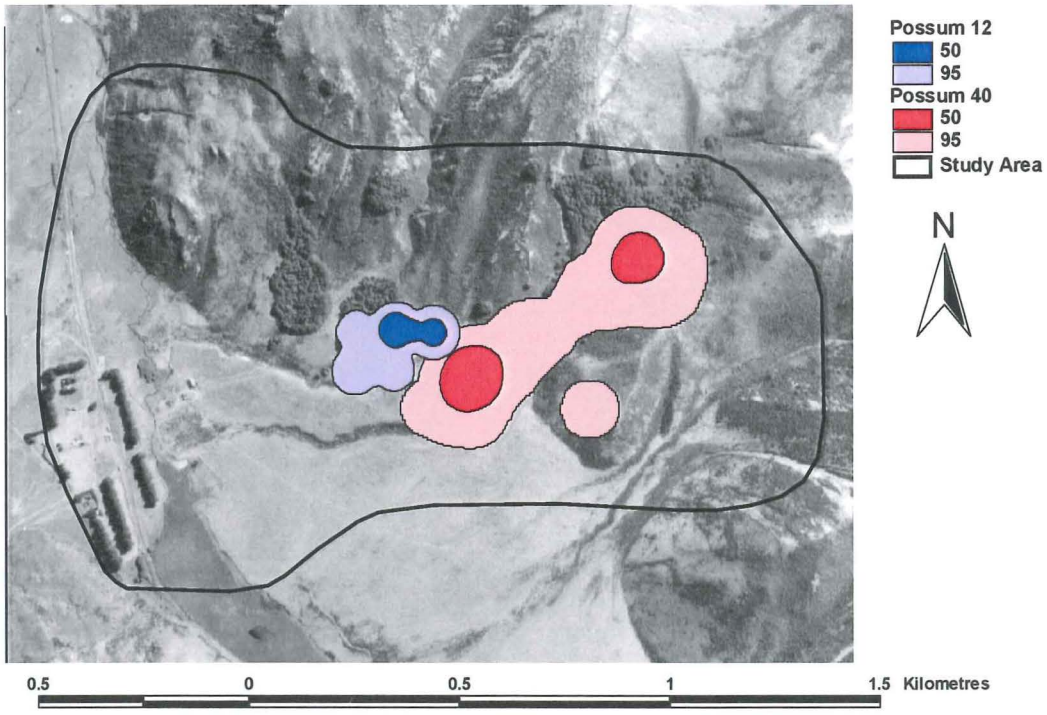

Figure 4.7 Kernel annual home range estimations of Possums 12, and 40 in the Cass study area.

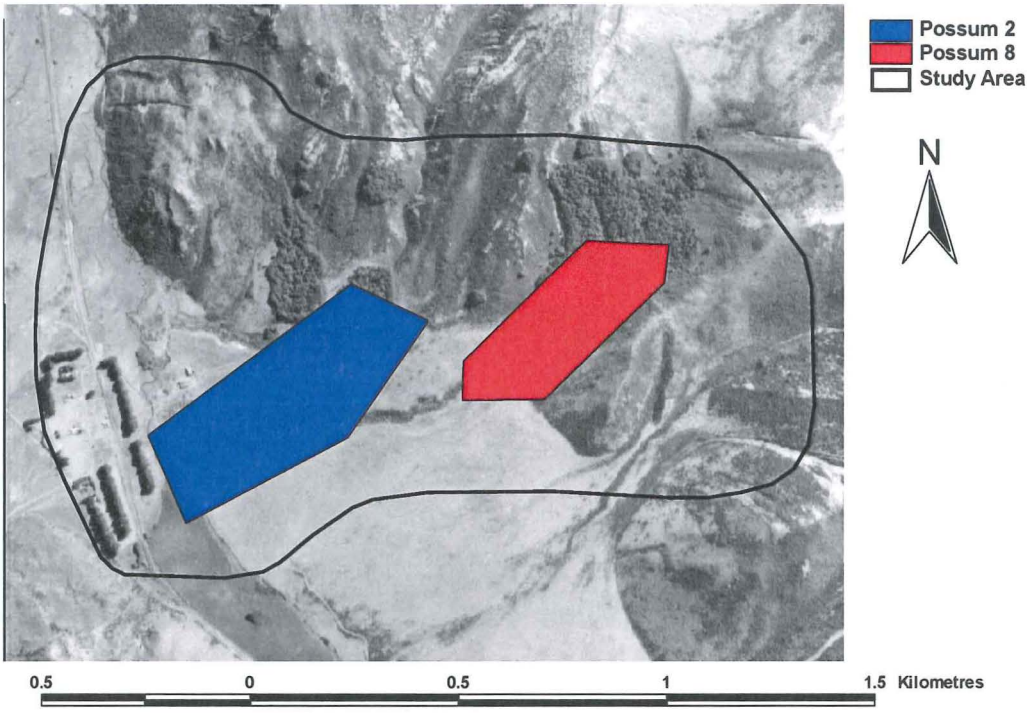

Figure 4.8 Minimum Convex Polygon annual home range estimations of Possums 2, and 8 in the Cass study area.

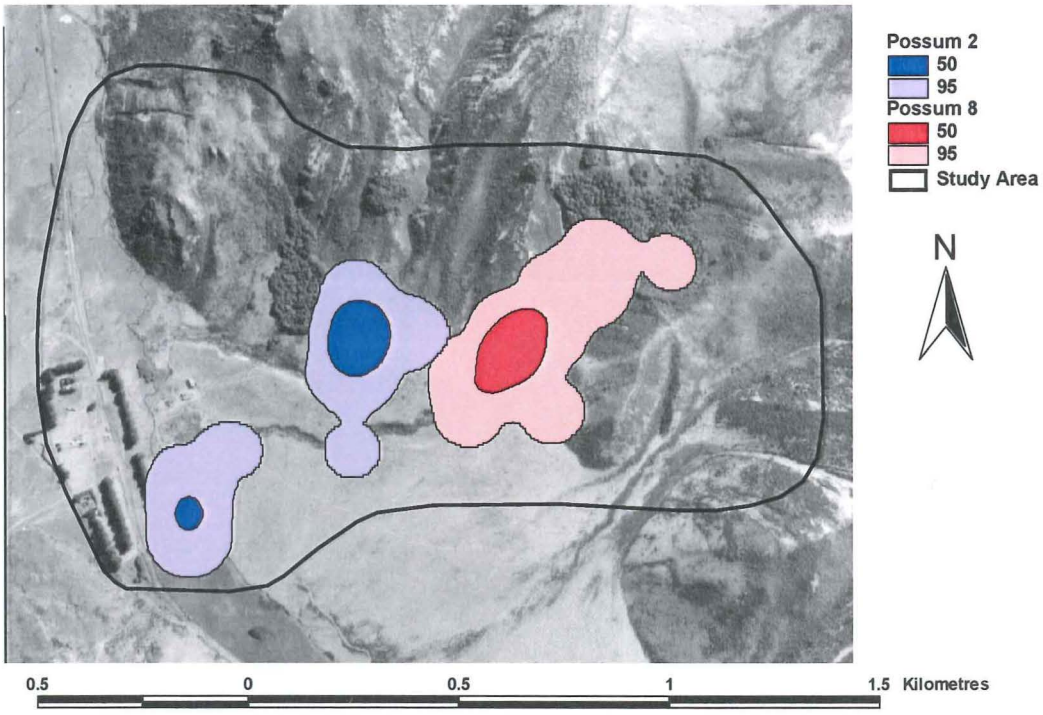

Figure 4.9 Kernel annual home range estimations of Possums 2, and 8 in the Cass study area.

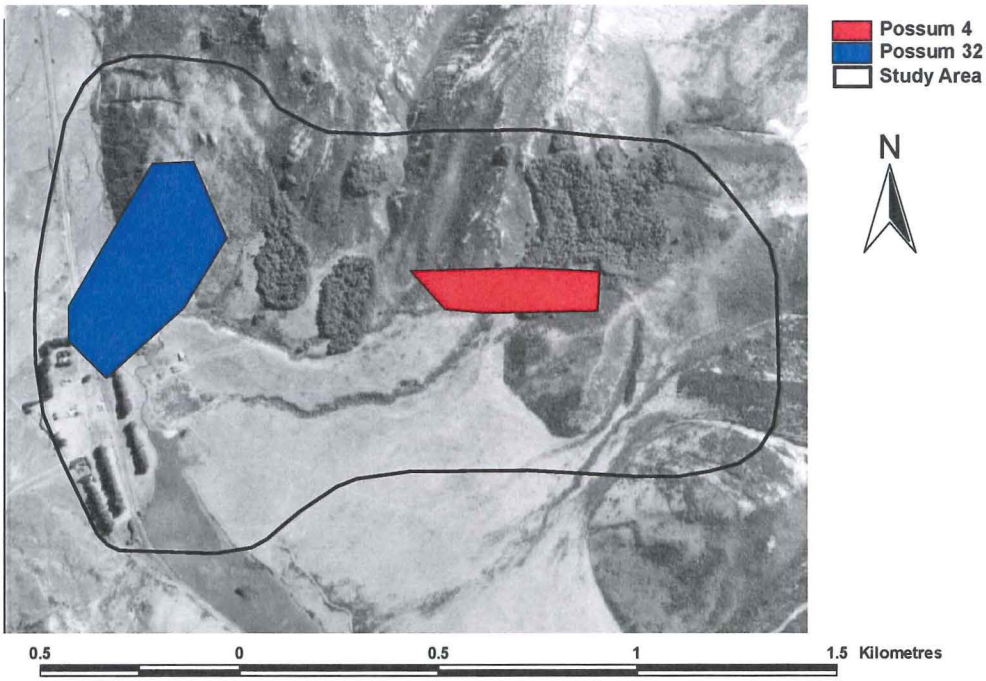

Figure 4.10 Minimum Convex Polygon annual home range estimations of Possums 4, and 32 in the Cass study area.

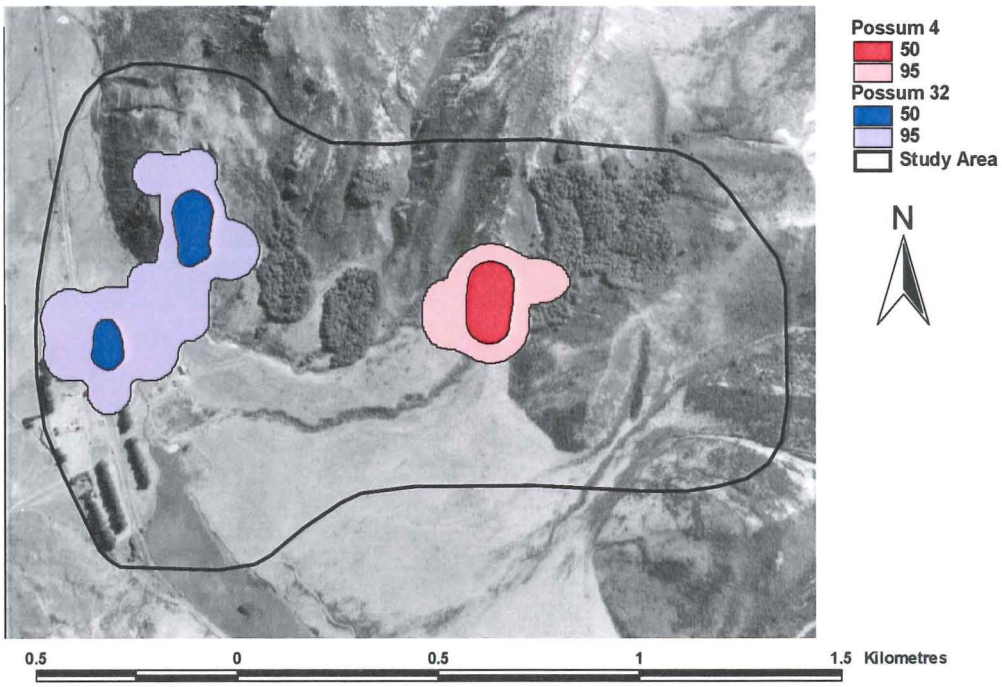

Figure 4.11 Kernel annual home range estimations of Possums 4, and 32 in the Cass study area.

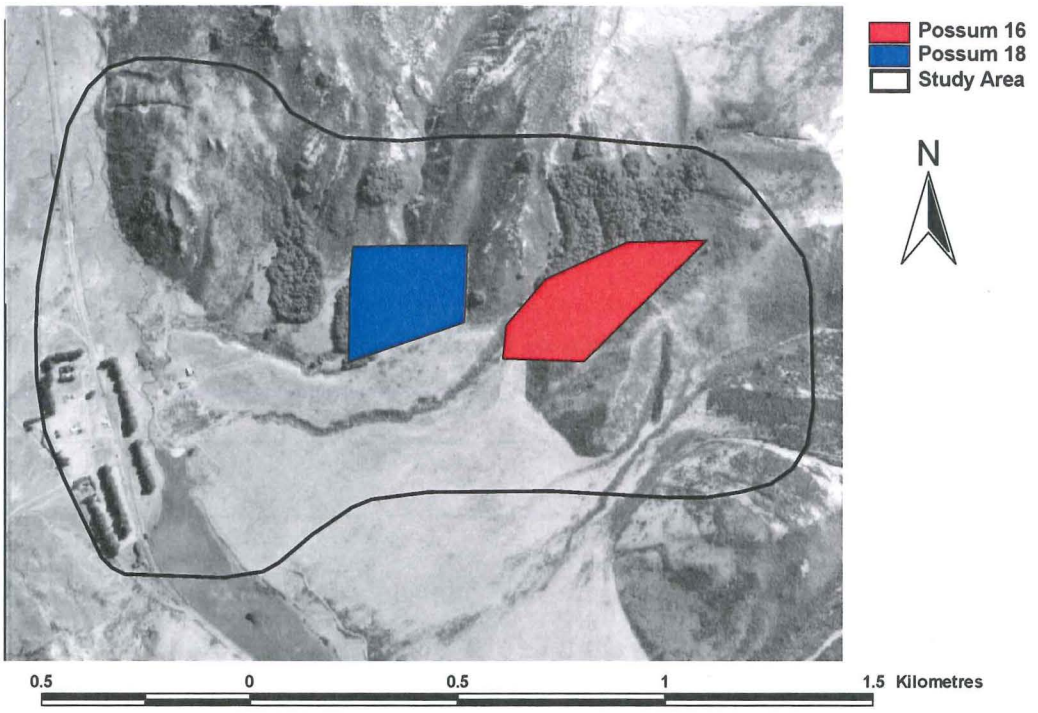

Figure 4.12 Minimum Convex Polygon annual home range estimations of Possums 16, and 18 in the Cass study area.

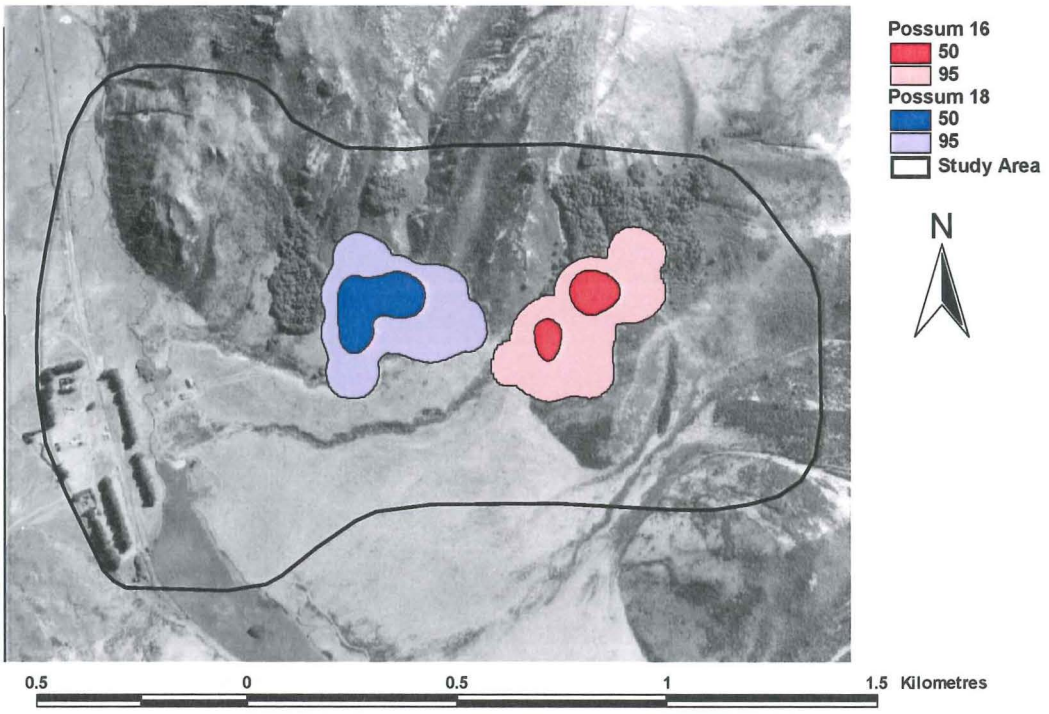

Figure 4.13 Kernel annual home range estimations of Possums 16, and 18 in the Cass study area.

4.3.5 Den sites

The area, which a possum uses as locations for den sites, varies from 1.0 ha to 9.7 ha. There are too few den site locations to enable accurate information concerning seasonal variation of possum den sites. Possums 2, 6, 8, and 32 have relatively larger areas where they den, when compared with the other possums used in this study (Table 4.7).

Table 4.7 Minimum Convex Polygon of annual possum den site area estimations (ha) from May 2000 to March 2001 in the Cass study area.

Possum	2	4	6	8	10	12	16	18	32	38	40
Area	9.7	3.9	6.9	9.1	2.5	4.6	2.0	1.2	8.9	1.9	1.0

The possums studied denned in either the scrub community or the forest community (Figure 4.14, Figure 4.15, and Figure 4.16). Of the possums that survived the entire radio-tracking period, Possum 4, 6, and 8 denned mainly in the scrub gullies (the main scrub gully that comes from Sugarloaf Bush; Figure 2.2). Possum 2 and 38 denned mainly in either the swamp community or the forest community. Possums 16 and 18 denned in both the forest community and the scrub community.

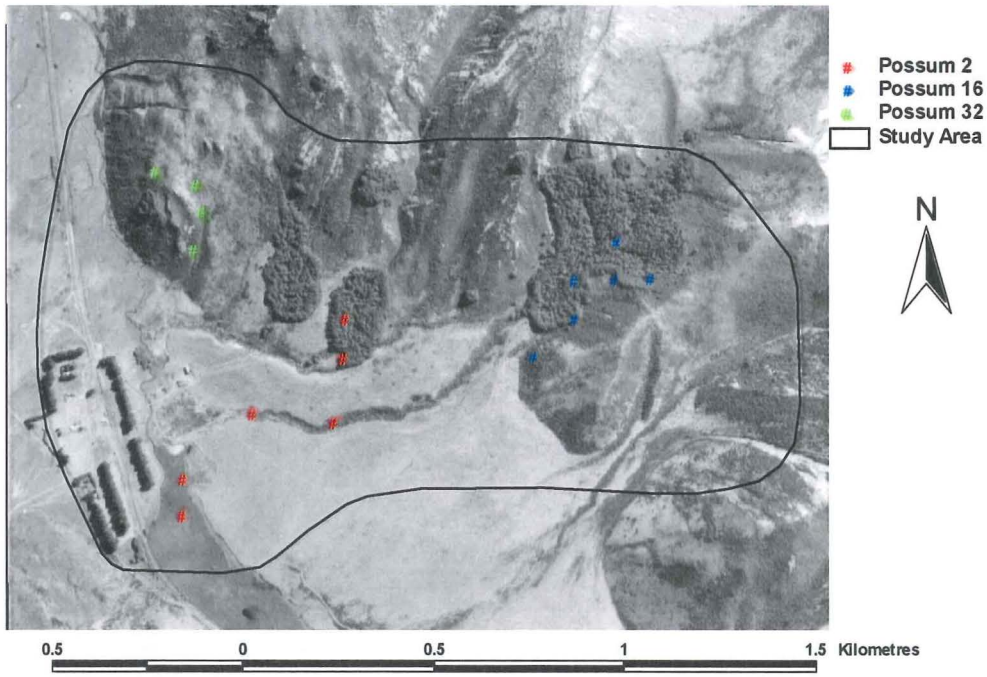

Figure 4.14 Den site position of Possums 2, 16, and 32, during the study period at the Cass study area.

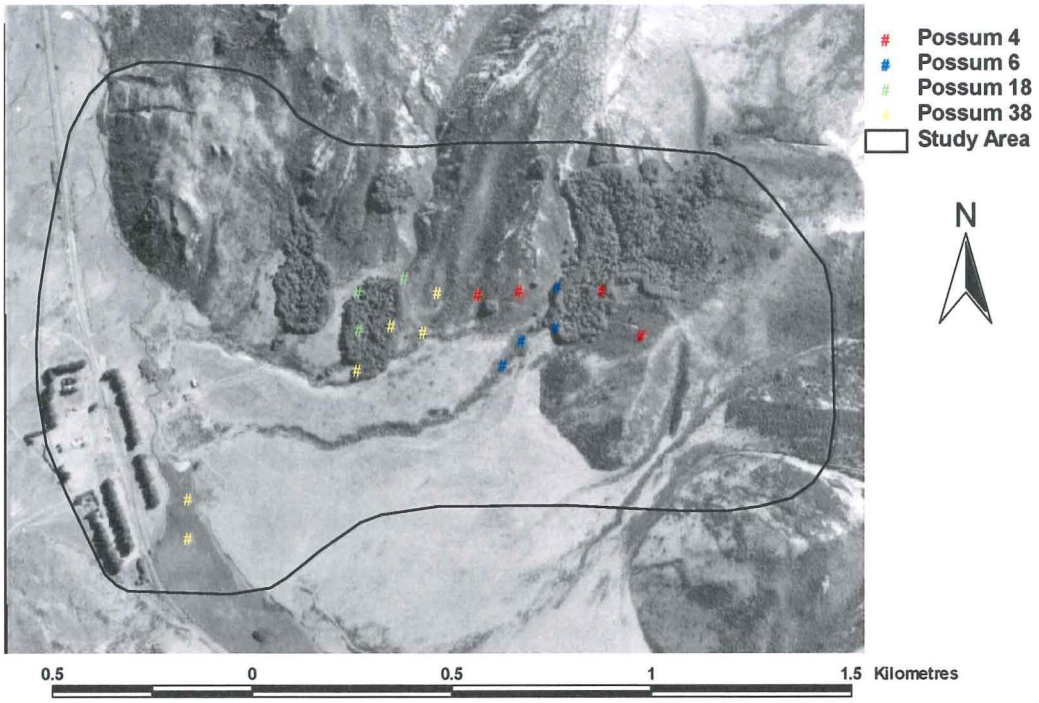

Figure 4.15 Den site position of Possums 4, 6 , 18, and 38, during the study period at the Cass study area.

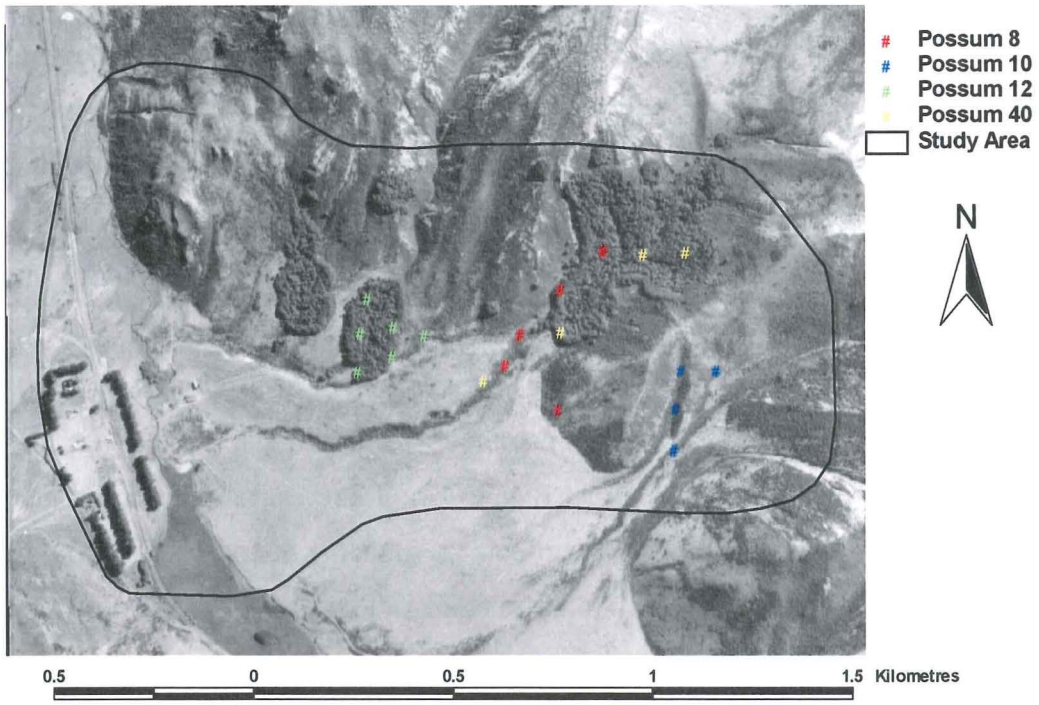

Figure 4.16 Den site position of Possums 8, 10, 12, and 40, during the study period at the Cass study area.

4.4 Discussion

Despite considerable effort spent in trapping and radio-collaring 12 possums, only eight possums provided sufficient high quality location data that could be used in determining possum home range size. A limitation affecting this study was insufficient funding to allow for radio-tracking more possums. A setback was the death of four of the radio-collared possums. When the possums were originally trapped, they were checked to see if they were in a healthy condition so that they would be able to survive the entire study.

4.4.1 Home range and range length

The results from this study do not support other studies that have found the general trend for male possums having a larger home range area than female possums (Table 4.8). At Cass, there was no statistical significant difference between female and male possum home range sizes.

In relation to the home range length, there was no statistically significant difference between male and female possums. Using the Kernel method there was 223 m difference between male and female possums, and when using the MCP method there was 218 m difference between male and female possums. The males had a larger home range length than females, although this was not statistically significantly different, therefore, Hypothesis 1 may be rejected. These results are similar to other possum studies conducted in New Zealand, in that male home range lengths tend to be larger than female home range lengths (Table 4.8).

Although this study does not statistically show that male possums having larger home ranges, past studies suggest this is common (Green, 1984). Possible reasons that male possum home range areas and home range lengths are larger than female possum home range areas and home range length are that males travel more in search of possible mates (Cowan and Clout, 2000), and that females do not have to travel large distances in search of a mate. Females must also conserve more of their energy so that offspring and mother will have a better chance of survival.

Possums existing on farmland tend to have larger home range areas than possums living in predominantly forested areas (Table 4.8). Environments that are largely spatially

heterogeneous tend to result in larger home ranges. The general reasoning for this phenomenon is that possums have to move further afield to reach areas with high quality resources in farmland areas. In addition, farmland that has remnant patches of forest and scrub tends to influence three types of possum home range behaviour (Cowan and Clout, 2000). The first type of behaviour occurs when a possum lives in an area where there are ample resources, thus resulting in the possum having a small home range as the possum does not need to travel far to reach all its required resources. The second type of possum home range behaviour may occur when a possum is living in areas such as forest margins. The possum tends to move further away, into patches of pasture and scrub, to feed. The other type of behaviour that is sometimes exhibited mainly in spatially heterogeneous habitats, but has been reported in a lowland podocarp-hardwood forest, is referred to as bimodal or 'dumbbell-shaped' behaviour (Cowan and Clout, 2000). Bimodal behaviour occurs when an animal has two core areas within their home range area. This type of behaviour occurs in the Cass study area with possums 2, 6, 16, 32, 38, 40. Therefore, hypothesis 5 may be accepted, as 60% of possums at Cass exhibited a bimodal ranging behaviour from the study period of May 2000 to March 2001. This type of behaviour is not normally reported in many possum movement studies (Cowan and Clout, 2000), but most likely occurs more frequently in spatially heterogeneous areas similar to Cass.

Bimodal behaviour tends to occur when there are some resources in one area and other resources in another area, which may, for example lead to a possum denning in one area but needing to forage in another area. This may be due to a lack of food resources in the denning area, and a lack of dens in the foraging area. Competition for resources may amplify this affect. A possum exhibiting bimodal behaviour may den in an area with plenty of dens, but through intraspecific competition may be unable to forage in the same area, thus the possum is forced to forage in another area. Due to the low possum density at Cass (Appendix 2), competition probably does not influence possum bimodal behaviour.

Table 4.8 Summary of New Zealand home range size and home range length data of possums in various habitats, updated from (Cowan and Clout, 2000), ranked from largest home range to smallest. Numbers in parentheses indicate the range of values. Type of home range movement methods is indicated (R, radio-tracking; S, spotlight; T, trapping).

Study Area	Home range area		Length		Reference	Methods
	Female	Male	Female	Male		
Pasture/scrub/willows	31.0	29.9	784	883	Brockie *et at.* 1987	R
Podocarp-mixed broadleaf forest	18.3	24.6	880	820	Green 1984	R
Pasture/scrub/remnant forest	10.2	11.9	536	759	de Zwart, this study.	R
Podocarp-mixed broadleaf forest	2.6	3.9	262	319	Ward 1978	R
Podocarp broadleaf forest	1.5	2.5	181	270	Ward 1984	R
Pasture/scrub/remnant forest	0.9	3.1	295	435	Jolly 1976	T
Pine, scrub, forest areas	1.3	1.9	190	210	Triggs 1982	T
Pine plantation	1.0	1.4	220	280	Clout 1977	T
Pasture/scrub/remnant forest	0.9	1.4	291	359	Paterson *et al.* 1995	R
Podocarp broadleaf forest	1.0	0.4	159	102	Ward 1984	T
Podocarp-mixed broadleaf forest	0.5	0.8	-	-	Crawley 1973	T, R, S
Pine plantation	0.7	0.7	230	310	Warburton 1977	T
Beech forest	-	-	390	529	Clout and Gaze 1984	T
Pine plantation	-	-	218	307	Keber 1988	T
Rata-kamahi forest	males tend to have larger home ranges				Green and Colman 1980	R

4.4.2 Seasonal home range variation

This study is not consistent with other studies in New Zealand in relation to seasonal variation, although these results may be caused by low sample size, especially in September and December. Generally, studies show that possums exhibit seasonal variation in their home range (Jolly, 1976; Ward, 1978; Thomas, *et al.*, 1984; Brockie, *et al.*, 1987). Therefore, Hypothesis 2 is rejected as possums in the Cass study area did not show any seasonal variation during the study period. Seasonal variation is generally influenced by seasonally available food (Cowan and Clout, 2000), such as fruit, fungi, flowers, seeds, and new leaves. A factor that may be influencing male seasonal home ranges is that males tend to move most extensively in summer and autumn (Green, 1984), probably in search of mates (Cowan and Clout, 2000). This trend was not detected in the Cass study area, possibly because all the seasonally available foods in each season was present throughout the entire study site so that possums did not need to change their home range between the different seasons in order to consume all their dietary requirements to survive. In addition, seasonal foods may not be preferred, or readily available, to possums in the Cass study area therefore resulting in no seasonal variation in possum home range. In addition, male

possums possibly did not have to travel far when searching for a mate.

4.4.3 Home range overlap and den sites

Possum home range overlap observed here is consistent with other studies in that possum overlap occurs within and between sexes (Dunnet, 1964; Crawley, 1973; Green, 1984; Paterson, *et al.*, 1995). Home range overlap is largely influenced by possum social interactions and possum density. The social interactions include aggressive interactions (competition for resources), and mother-offspring interactions (Day, *et al.*, 2000).

Aggressive interactions increase when population density increases. The possum population is low at Cass, therefore aggressive interactions, such as competition for food and den sites will be relatively low. This suggests that possum home range should not overlap much, but the results show that all of the remaining possums overlapped their home range with another possum. This probably means that the possum resources are spatially distributed throughout the heterogeneous study site. Therefore there are patches of food resources and patches of den sites throughout the study site, resulting in possum home ranges overlapping with each other when the possum is searching for these resources.

Young females tend to establish home ranges close to their mothers, thus increasing their chances of home range overlap (Clout and Efford, 1984). Young males generally move to new areas once they have left their mother. The general trend for young males is that their home ranges tend to shift gradually further away from their mothers' (Efford 1991, in (Cowan and Clout, 2000).

Competition for resources will increase if other possums start foraging and denning in areas that belong to another individual's core home range area. Low densities of possums in the area will enable possums to move more freely around, without having to come into contact with other possums, and therefore they will have less contact with another possum's core home range area. This reduces the amount of social interaction, and competition for resources that each possum will experience hence this may facilitate overlap.

Possums at Cass show a high proportion of possums sharing home range areas, as well as

core home range areas. Female-female, female-male, and male-male home range and core home range areas overlap. Although the home range and core home range areas overlap, this does not mean that the possums will enter each other's home range areas when the other possums are in the area. The causes of this overlapping may be that areas of good forage availability and high quality den sites only occur in certain areas, which is probably common in spatially heterogeneous areas similar to Cass. From these results, Hypothesis 4 is rejected as over 50% of possums studied (including possums that died during the study period) exhibited some kind of possum home range overlap. Of the possums that survived the entire study, all of them had home ranges that overlapped with at least one other possum which was studied. The possum home range overlapping results are probably underestimated as only a sub-sample of possums were radio-tracked.

Possums studied at Cass did not share the same dens, but they did den in the same area. This is probably due to the high proportion of available den sites in relation to low possum density. However, that the sample possums did not share the same dens does not necessarily mean that other possums at Cass do not share den sites. In the forested areas there appeared to be little den availability for the possums. Within the forested area's there was little regeneration of plant species other than *Nothofagus solandri* (Figure 3.9). The radio-tracking results found few possums denning in fallen logs, but most appeared to den high up in the canopy. The dens often are in holes near the crowns of the trees. The majority of the possums denned in the scrub communities. Possums have few ground predators in New Zealand therefore denning in the scrub areas is relatively safe. At Cass, the scrub communities where the possums denned are very densely vegetated (Figure 3.7 and Figure 3.8). There is little regeneration beneath the dense scrub communities, which suggests that little light reaches the ground level for new plants to establish. This makes a dark and safe den site for possums.

Generally, possums have between five and 15 den sites within their home range (Green and Coleman, 1986a; Cowan, 1989). Although none of the radio-tracked possums denned communally, this might occur at Cass, but since possum density is low in this area, communal denning will be rare. Therefore, Hypothesis 3 may be accepted: Possums in the study area did not share the same den site with other possums over the study period.

The denning areas for each possum ranged from large to small. This is probably related to

the spatially heterogeneous landscape at Cass. This suggests that there are limited den sites throughout Cass, which resulted in some possums having to travel large distances to find a den site, such as the two possums that travelled from Middle Bush down to the swamp, and Possums 6 and 8 travelled from Sugarloaf Bush down to the gully that is surrounded by shrubland. Other factors may influence these results, such as food availability, and intraspecific competition.

4.5 Summary

Female and male possum home range areas and home range length were not statistically significantly different in the Cass Study Period from May 2000 to March 2001. This result is not consistent with other possum home range studies, and the reasons for this may be attributed to low possum sample size, males travelling further to find mates, or that females must conserve more energy than male possums so that them and their offspring have a higher chance of survival. This may also be related to low sample size.

There was no statistical significant difference between the seasons in the Cass study area from May 2000 to March 2001. Other possum home range studies have found seasonal differences in home range. Reasons for why there is no seasonal difference in home range in this study may be attributed to the low sample size, seasonally available food being distributed throughout the study in high numbers, or that seasonal foods are not preferred, or readily available, to the possums. Low sample size may also a key factor to these results.

Possums at Cass did not share the same den sites with other possums over the period May 2000 to March 2001. This result is similar to other possum home range studies that have a low possum density, similar to the Cass study area. This may also be attributed to low sample size.

Over 50% of possums studied at Cass over the period May 2000 to March 2001 exhibited home range overlap. The overlapping of home ranges probably occurs as the landscape is spatially heterogeneous therefore the resources (i.e. food, den sites) are likely to be in patches throughout the study area, therefore possums will have overlapping home ranges in order to use these resources.

Sixty percent of the possums studied at Cass over the period May 2000 to March 2001 exhibited bimodal ranging behaviour. Bimodal behaviour probably results from some resources being in one area and other resources being in other areas throughout the spatially heterogeneous study area, which results in the possum having to travel long distances in order to use all the resources for survival. This behaviour may also be associated to competition between other possums and possibly other animals, thus resulting in the possum not being able to get all required resources in one area, consequently possums need to travel long distances to receive other resources.

Therefore, conclusions about possum movement at Cass are that the spatially heterogeneous landscape, and low possum density influence large possum home range, bimodal behaviour, and large den site areas.

Chapter 5 Possum diet

5.1 Introduction

Possum diet, based mainly in native forest systems, has been widely studied throughout New Zealand (Mason, 1958; Gilmore, 1967; Fitzgerald, 1976; Fitzgerald, 1978; Fitzgerald and Wardle, 1979; Coleman, *et al.*, 1985; Cowan and Moeed, 1987; Cowan, 1990b; Owen and Norton, 1995; Allen *et al.*, 1997; Cochrane *et al.*, 2003). Possums also forage to a lesser extent in exotic pasture-lands (Gilmore, 1967; Harvie, 1973; Coleman, *et al.*, 1985), exotic forests (Clout, 1977; Warburton, 1978), and native mixed systems (Gilmore, 1967; O'Cain, 1997). The main food group that possums utilise is foliage.

Possums are hind-gut fermenting herbivores, which is a common digestive strategy for small folivores. This strategy is not highly developed in possums, which consequently results in a greater requirement for energy-rich/high nutrient foods (Nugent *et al.*, 2000). Because possums require such energy-rich foods they are known as generalist and opportunist feeders and, as such, are able to occupy a range of habitats (Cowan, 1990a).

The first objective of this chapter is to quantify female and male possum diet, and to determine whether there is a difference in diet between the sexes at Cass. This aspect will be studied in this chapter because there are two factors which, combined, may result in female possums having a higher quality diet. First, female possums are generally more dominant than male possums (Jolly and Spurr, 1996). Furthermore, females probably need to consume more foods high in essential vitamins, nutrients and fats; which are important to the female possum and the embryonic nurturing stage of the newborn joey. Pregnancy lasts 18 days, and lactation lasts approximately six months (Tyndale-Biscoe and Renfree, 1987). Possum milk is comprised mostly of carbohydrates and protein (Fletcher and Selwood, 2000).

The second objective of this chapter is to determine whether there is evidence of a difference in diet between juvenile and adult possums at Cass. Such differences may arise, even though published research does not discuss this aspect. Juvenile possums are generally subordinate to the larger older possums (Jolly, 1976; Biggins and Overstreet, 1978). It has been found in both wild and captive situations that subordinate possums will temporally and spatially segregate from dominant possums (Jolly, 1973). From these

findings it can be suggested that through competition, juvenile possums may have a diet that is different and probably inferior to that of adult possums. The differences will probably occur in consumption of seasonally available food, which are often higher in nutrients, vitamins, and fats.

The third objective of this chapter is to determine whether there is a seasonal difference in the diet of possums at Cass. Seasonal factors such as fruits, flowers, fungi, seeds, and spring flush in foliage growth, are generally short-term. The proportion of these foods in the possum diet is related to availability. Other possum diet studies have found seasonal differences in their diet (Gilmore, 1967; Harvie, 1973; Clout, 1977; Warburton, 1978; Coleman, *et al.*, 1985; Cowan, 1990b; Owen and Norton, 1995; Allen, *et al.*, 1997; Nugent *et al.*, 1997; Rogers, 1997; Sellar, 1998).

The fourth objective of this chapter is to determine whether possum diet in the Cass study area comprises predominantly foliage, as has been found in most possum diet studies. (Nugent, *et al.*, 2000).

The fifth objective of this chapter is to determine if possums at Cass will have between three to five dominant food species in their diet. Three to five food species tend to make up the majority of a possum's stomach content in most other studies (Nugent, *et al.*, 2000). This indicates that possums spend long periods of their foraging time eating one food species before they forage elsewhere.

The following hypotheses have been formulated for possums in the study area:

1) There is a difference between female and male possum diet.
2) There is a difference between juvenile and adult possum diet.
3) There is a seasonal difference in possum diet.
4) There is a difference between quantity of foliage and other food types in possum diet.
5) Between three and five food species will dominate possum diet.

5.2 Methods

The diet of possums in the Cass study area was studied at four different times through 2001

(March, June, September, and December). The March sample was collected after the final radio-tracking period, so as not to compromise the possum radio-tracking study.

5.2.1 Stomach collection

Initially a sample of 15 - 20 possums was sought for each testing period, but later in the study the possum trap-catch rate declined markedly, which resulted in a limited number of possums caught for the last two samples. Fifteen Timms kill-traps were set (Figure 5.1) and baited with apple and cinnamon. Traps were set for a maximum of six nights, but if 15 to 20 possums were caught before this period ended, the traps were taken out. Possum stomachs were removed in the field, and frozen as soon as practical. Timms traps were placed in the same areas at each sample (Figure 5.2). Trap locations were based on areas where possum sign was seen, and in areas that were suitable (i.e. in areas of flat ground, and generally next to a support such as trees or fence posts). Possum samples were located in areas where the radio-tracked possums were caught, therefore increasing the probability of this diet study being more relevant to the radio-tracked possums. Each possum caught was weighed and sexed in the field. Ethics approval for this capture methodology was granted from the University of Canterbury Animal Ethics Approval Committee.

Figure 5.1 A successful catch using a Timms® trap.

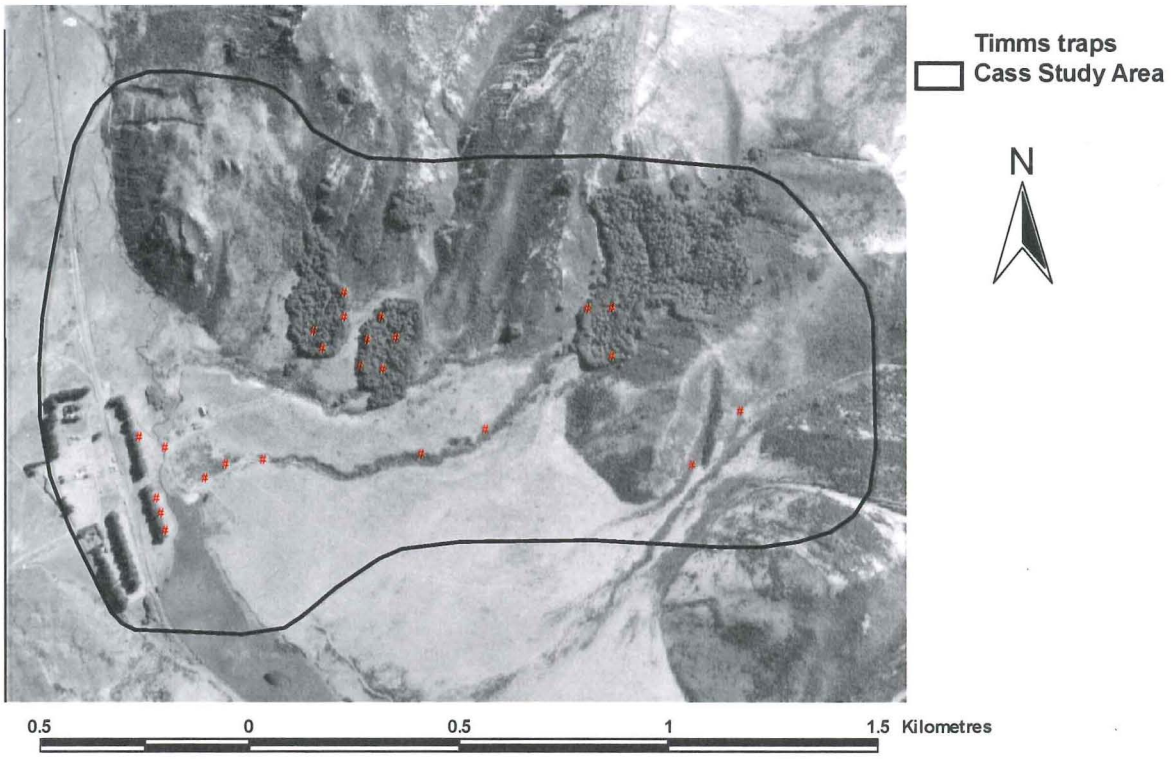

Figure 5.2 The location of Timms® traps throughout 2001 in the Cass study area.

5.2.2 Stomach analyses

Two macroscopic methods for analysing possum stomachs are commonly used in New Zealand: the point-sampling technique (systematic sub-sampling sieving technique), and the layer-separation technique (physical separation) (Sweetapple and Nugent, 1998). The point-sampling technique tends to underestimate the proportions of food groups with small average fragment size, and overestimate items with large average fragment size (Sweetapple and Nugent, 1998). Plant identification tends to be easier with the layer-separation technique, especially for otherwise unidentifiable stems and fibres, as these parts of plants are identified by the layer in which they occur. When they occur, the different layers in the possum stomachs are generally easy to distinguish. Therefore, for stomachs with easily identifiable layers, the layer-separation technique is preferable. If large parts of the possum stomach are layered, but small proportions are mixed, it is best to use the layer method to analyse the layered section, and to then use either the point-sampling method or simple estimation by eye of the relative significance of species, for the mixed area (Sweetapple and Nugent, 1998). Combining both methods is likely to increase accuracy in diet analysis (Sweetapple and Nugent, 1998).

In the Cass study area, the possum diet was assessed using the point-sampling method only, using the dry weight and frequency of occurrence for each food species present. The point sampling method was used as the majority of the stomach samples were mixed, thus making it impractical to use the layer method. The reason for this is probably due to the possums spending less time at one food source before moving to another food source (P. Sweetapple, pers. comm.). If the possum continuously does this throughout the foraging period, than the different food types present are not easily distinguished as distinct layers.

5.2.3 Diet analysis

Possum stomachs were thawed and rinsed over a 3 mm sieve to remove fine material. The fine material was generally unidentifiable when using the point-sampling technique and quite often the dry weight was insignificant. Species that do not have any significant dry weight were lost from the data set if recording the dry weight only. Therefore it is preferable to look at results for both the dry weight data with frequency of occurrence of different food species. The sieved material was placed in a large rectangular container that

contained a 10 × 10 dot grid. The diet fragments that were located above the dots were taken out and identified by comparing to preserved plant material using a dissecting microscope. Sieved material was recorded by frequency of occurrence and dry weight, and then sorted to genus and species levels (if possible). Dry weight food items were oven-dried at 80˚C, and then weighed.

Individual food items were sorted into the following food groups (foliage, fungi, bark, litter, seed, fruit, black mould (from *Nothofagus solandri* bark), flower, moss, feather, and insect). Differences in the mean percent frequency of occurrence and dry weight of the diet samples were analysed using Spearman Rank correlation.

5.3 Results

Forty-nine possums were captured for the purpose of this study. The March and June provided a total of 16 and 18 stomachs respectively, and the September and December provided nine and eight stomachs respectively (Table 5.1). Female and male ratios of trapped possums were similar in March and June, but in September and December more males than females were trapped (Table 5.1). All possums samples (seasonally) included juvenile possums, and both adult females caught in September had joeys. The stomach contents of the joeys were not used because the joeys were still suckling. The low sample of possum stomachs at the last two sample periods is likely to induce some error in the results, but this was unavoidable because of the originally low overall possum density in the study area (Appendix 3: Possum density estimate).

Table 5.1 Total possums caught per season (March 2001, June 2001, September 2001, and December, 2001).

Possums		Mar-01	Jun-01	Sep-01	Dec-01
Female	Juvenile	2	3	1	2
	Adult	6	5	2 (2 Joeys)	0
Male	Juvenile	2	3	3	1
	Adult	6	7	3	5
Total		16	18	9	8

5.3.1 Gender and age

There was no significant statistical difference in diet composition between male and female possums annually or for any of the individual sample periods (Table 5.2, Appendix 3). There was also no significant statistical difference in diet between adult and juvenile animals for the same sample periods, except for June 2001 (Table 5.3). Given this significant similarity in diet and due to the low sample size all possum samples were pooled by sample period for further analysis.

Table 5.2 Spearman rank correlation coefficients calculated between male and female possums using all food items based on their frequency of occurrence and dry weight in stomachs.

	% Dry Weight		Frequency	
	R	P	R	P
Mar-01	0.792	0.002	0.748	<0.001
Jun-01	0.861	<0.001	0.473	0.003
Sep-01	0.866	<0.001	0.604	<0.001
Dec-01	0.745	0.005	0.459	0.004
Total	0.423	0.018	0.611	<0.001

Table 5.3 Spearman rank correlation coefficients calculated between adult and juvenile possums using all food items based on their frequency of occurrence and dry weight in stomachs.

	% Dry Weight		Frequency	
	R	P	R	P
Mar-01	0.634	<0.001	0.628	<0.001
Jun-01	0.285	0.071	0.250	0.125
Sep-01	0.521	0.001	0.572	0.001
Dec-01	0.626	<0.001	0.618	<0.001
Total	0.535	0.003	0.464	0.003

5.3.2 Diet

5.3.2.1 Food groups

The overall diet of possums in the Cass study area was dominated by foliage (Table 5.4). Other food groups were relatively unimportant overall, although their importance varied (Table 5.4). There was an overall significant statistical difference between the seasonal usage of food groups (Table 5.5).

Foliage was consumed by all sampled possums during the study period, with the percent dry weight ranging from 63.2% in March to 85.3% in December (Table 5.4). The annual

percent dry weight was 72.7%.

Fungi is the second most important food group which was present in March, June, and December, with June having the highest proportion (17.0%), although only a small proportion of possums consumed fungi (24% overall) (Table 5.4).

Bark was the third most important food group and was consumed mainly in September, making up 22.9% of diet (Table 5.4). The highest proportions of litter were present in March and June, and litter appeared to be unimportant in September and December.

Seeds were relatively important in March with 16.6%, making them the fifth largest food group (Table 5.4). Fruit was ranked the sixth most important food group in the possums' diet, occurring in December (15.3%) and March (6.6%), but was found in only a few possum stomachs throughout the study (Table 5.4).

Black mould appeared to be relatively dominant in June only, making up 11.0% of diet, but in only 11.1% of possum stomachs studied (Table 5.4). Flowers, moss, feathers, and insects were not consumed in high quantities and show little or no seasonal difference (Table 5.4).

Flowers were consumed by 87.5% of sample possums in small portions (Table 5.4). However, the frequency of occurrence results suggests that possums consumed more flowers than was indicated by the dry weight results (Appendix 3). This suggests that there is a seasonal difference in possum consumption of flowers.

Table 5.4 Seasonal differences (March 2001, June 2001, September 2001, and December 2001) in possum diet in the Cass study area showing dry weight (%DW) of food groups present in their diet. t, represents trace amounts of food of food material in possum diet. "-", represents nil occurrence of food material in possum diet.

	Mar-01		Jun-01		Sep-01		Dec-01		Annual	
Food Type	%DW	%N	%DW	%N	%DW	% N	%DW	%N	%DW	%N
Foliage	63.2	100.0	65.6	100.0	76.8	100.0	85.3	100.0	72.7	100.0
Fungi	7.8	25.0	17.0	33.3	-	-	9.0	37.5	8.4	24.0
Litter	8.8	37.5	10.4	88.9	3.5	55.6	2.0	50.0	6.2	58.0
Bark	0.8	12.5	-	-	22.9	22.9	-	-	5.9	8.9
Fruit	6.6	6.3	-	-	-	-	15.3	12.5	5.5	4.7
Seed	16.6	81.3	2.2	22.2	-	-	-	-	4.7	25.9
Black mould	-	-	11.0	11.1	-	-	-	-	2.8	2.8
Flower	-	-	-	-	-	-	2.8	87.5	0.7	21.9
Moss	-	-	1.0	16.7	t	11.1	-	-	0.3	7.0
Feather	t	6.3	-	-	-	-	-	-	t	1.6
Insect	-	-	-	-	-	-	t	12.5	t	3.1

Table 5.5 Spearman rank correlation analysis showing correlations (and *P*-values in brackets) in percentage dry weight between different seasons (March 2001, June 2001, September 2001, and December 2001) in food groups in the Cass study area.

	Mar-01	Jun-01	Sep-01	Dec-01
Mar-01	1.000	0.479 (0.098)	0.361 (0.226)	0.471 (0.104)
Jun-01		1.000	0.354 (0.235)	0.425 (0.148)
Sep-01			1.000	0.351 (0.240)
Dec-01				1.000

5.3.2.2 Individual food types

Twenty-five different foliage species were identified in the possum samples throughout the study period, and 38 different food items were consumed by possums over the study period (Table 5.6). While similar numbers of food items were recorded in possum stomachs in each of the sampling periods (17-28), there was considerable variation in the number of species consumed at different times (Table 5.6). Four food items, *Aristotelia fruticosa*, fungi, *Blechnum penna-marina*, and *Podocarpus nivalis*, make up 50% of the total diet (Table 5.6). Overall, there was a statistically significant difference between the seasons (Table 5.7), except that the December diet was similar to those of March and June. However, these latter two samples were dissimilar and the September diet differed from those of all other months (Table 5.7).

The diet in March was dominated by *Aristotelia fruticosa* (foliage and seed), *Rubus schmidelioides*, *Pittosporum divaricatum*, litter and fungi. *Aristotelia fruticosa* was present in high proportions throughout this study, and in a high proportion of individual possum samples.

Rubus schmidelioides and *Pittosporum divaricatum* were dominant only in March, and were present in less than 50% of the possum samples (Table 5.6). Litter had its highest proportions in March (8.7%) and June (10.4%), but was found in few possum samples in March (37.5%), and in a high proportion of possum samples in June (88.9%).

In June, *Aristotelia fruticosa* (40.6%), fungi (16.9%), and litter (10.4%) were the dominant food items (Table 5.6). *Aristotelia fruticosa* and litter were found in over 83% of the possum stomachs studied. Fungi were present in 33.3% of possum samples.

By September, the dominant food items present were bark (22.9%), *Podocarpus nivalis* (21.7%), *Aristotelia fruticosa* (16.1%), and exotic grass (13.4%) (Table 5.6). These were found in a relatively high proportion of possum samples tested in this study.

Blechnum penna-marina (28.5%), *Aristotelia fruticosa* (17.5%), and *Mycelis muralis* (12.5%) dominated possum diet in December, and all were found in a high proportion of possum samples (Table 5.6).

Seasonal variation occurs between fungi, seeds, fruits, herb, and flowers. A bias may occur within these food groups, which can be seen in Table 5.6. The majority of these food groups were present in a small proportion of possum stomachs. Fungi were present in March, June, and December, with June having the highest proportion (16.9%). Fungi were seen in only 33.3% of the possum stomachs. Seeds (from *Aristotelia fruticosa* and *Myrsine divaricata*) were present in March and June, with March containing the highest proportion (16.6%) and seeds were found in the majority of stomachs (62.5%). Fruit (from *Ribes ovacrispa* and *Rubus squarrosus*) occurred in possum diet in March and December in small amounts and in a small proportion of possum stomachs. *Cytisus scoparius* flower was the only flower that was found in the possum diet, and was present in a high proportion of the stomachs (87.5%).

Table 5.6 Seasonal differences (March 2001, June 2001, September 2001, and December 2001) in possum diet in the Cass study area showing dry weight (%DW) of food types present in possum diet. %N represents percentage of occurrence in possum's stomachs of food material. t, represents trace amounts of food material in possum diet. - represents nil occurrence of food material in possum diet.

	Mar-01		Jun-01		Sep-01		Dec-01		Annual	
FOOD TYPE	%DW	%N	%DW	%N	%DW	%N	%DW	%N	%DW	%N
Aristotelia fruticosa	32.4	87.5	40.6	83.3	16.1	66.7	17.5	62.5	26.7	75.0
FUNGI	7.8	25	16.9	33.3	-	-	9.0	37.5	8.4	24.0
Blechnum penna-marina	2.3	25	t	16.7	-	-	28.5	50.0	7.7	22.9
Podocarpus nivalis	0.6	12.5	1.8	33.3	21.7	44.4	4.6	87.5	7.2	44.4
BARK	0.4	12.5	-	-	22.9	55.6	-	-	5.8	17.0
LITTER	8.7	37.5	10.4	88.9	1.8	55.6	1.0	50.0	5.5	58.0
EXOTIC GRASS	0.2	12.5	1.8	61.1	13.4	77.8	5.9	75.0	5.3	56.6
Mycelis muralis	2.8	25	1.7	33.3	-	-	12.5	62.5	4.3	30.2
Aristotelia fruticosa (seed)	16.6	62.5	t	11.1	-	-	-	-	4.1	18.4
Rubus schmidelioides	11.4	12.5	0.1	11.1	-	-	1.7	25.0	3.3	12.2
Nothofagus solandri	0.3	6.25	2.0	55.6	6.9	44.4	1.3	25.0	2.6	32.8
HERB	-	-	2.4	33.3	5.4	33.3	2.6	12.5	2.6	19.8
Pittosporum divaricatum	9.1	43.8	0.3	5.6	-	-	-	-	2.4	12.3
Muelenbeckia axillaris	-	-	6.3	16.7	2.4	11.1	-	-	2.2	6.9
Ribes ova-crispa (fruit)	-	-	-	-	-	-	7.7	12.5	1.9	3.1
Trifolium repens	0.4	12.5	t	22.2	3.1	11.1	2.6	62.5	1.5	27.1
PETIOLES	1.5	18.8	1.2	5.6	1.5	11.1	1.8	12.5	1.5	12.0
BLACK MOULD	-	-	5.5	11.1	-	-	-	-	1.4	2.8
Aristotelia serrata	-	-	4.0	5.6	-	-	-	-	1.0	1.4
Rubus squarrosus (fruit)	3.3	6.3	-	-	-	-	-	-	0.8	1.6
Celmisia gracilenta	-	-	-	-	3.0	11.1	-	-	0.7	2.8
Myrsine divaricata	1.0	12.5	0.5	11.1	-	-	1.2	12.5	0.7	9.0
Myrsine divaricata (seed)	-	-	2.2	11.1	-	-	-	-	0.5	2.8
Cytisus scoparius (flower)	-	-	-	-	-	-	1.4	87.5	0.4	21.9
Acaena inermis	0.9	18.8	0.1	16.7	t	33.3	0.1	12.5	0.3	20.3
Coprosma species	-	-	t	5.6	1.1	11.1	-	-	0.3	4.2
Ozothamnus leptophylla	-	-	0.8	5.6	t	11.1	-	-	0.2	4.2
Hypochoeris radicata	-	-	t	5.6	-	-	0.7	12.5	0.2	4.5
Leptospermum scoparium	-	-	-	-	0.8	11.1	-	-	0.2	2.8
Poa colensoi	-	-	0.8	11.1	-	-	-	-	0.2	2.8
Coriaria sarmentosa	0.2	6.3	t	5.6	-	-	-	-	t	3.0
MOSS	-	-	0.5	16.7	t	11.1	-	-	0.1	6.9
Acaena inermis (seeds)	t	18.8	-	-	-	-	-	-	t	4.7
Cyathodes colensoi	-	-	-	-	t	22.2	-	-	t	5.6
Pimelia fraseri	t	6.3	t	11.1	-	-	-	-	t	4.3
Viola cunningham	-	-	t	5.6	-	-	-	-	t	1.4
FEATHER	t	6.3	-	-	-	-	-	-	t	1.6
INSECT	-	-	-	-	-	-	t	12.5	t	3.1

Table 5.7 Spearman rank correlation analysis showing correlations (and *P*-values in brackets) between seasonal differences (March 2001, June 2001, September 2001, and December 2001) in possum food types at the Cass study area. %DW, percentage dry weight of food groups present in their diet.

	Mar-01	Jun-01	Sep-01	Dec-01
Mar-01	1.000	0.240	0.155	0.497
		(0.147)	(0.351)	(0.002)
Jun-01		1.000	0.286	0.324
			(0.082)	(0.047)
Sep-01			1.000	0.295
				(0.072)
Dec-01				1.000

5.4 Discussion

5.4.1 Gender and age

There was no significant statistical difference between the female and male diets in the Cass study area over the study period. Therefore the Null Hypothesis 1 is rejected. This result is consistent with most other possum diet studies throughout New Zealand and Australia which also found that the diets of female and male possums are statistically similar (Mason, 1958; Gilmore, 1967; Harvie, 1973; Fitzgerald, 1976; Fitzgerald and Wardle, 1979; Fitzgerald, 1984; MacLennan, 1984; Owen and Norton, 1995; Nugent, *et al.*, 1997; Sellar, 1998; Cochrane, *et al.*, 2003). In contrast, Coleman, *et al.*, (1985) found that female and male possum diet did differ for certain food groups, although the significantly different food types comprised only 5.2% of total diet. It can be argued that female possums will probably need energy-rich foods more than males during the lactation period, especially during the 18 day gestation period, and for approximately six months of lactation (Tyndale-Biscoe and Renfree, 1987), although the research does not show this.

There was also no statistically significant difference between the juvenile and adult possum diets in the study area over the duration of the study. Therefore Null Hypothesis 2 is rejected. This result is similar to those of other New Zealand and Australian studies (Mason, 1958; Gilmore, 1967; Harvie, 1973; Fitzgerald, 1976; Fitzgerald and Wardle, 1979; Fitzgerald, 1984; MacLennan, 1984; Coleman, *et al.*, 1985; Owen and Norton, 1995; Nugent, *et al.*, 1997; Sellar, 1998; Cochrane, *et al.*, 2003), which have also found no difference between juvenile and adult possums.

5.4.2 Diet

Possum diet in New Zealand has been studied extensively throughout a variety of vegetation types. From these studies it has been accepted that possums are opportunistic polyphagic feeders, consuming a variety of different food items from a range of food groups. The results here support many of the earlier findings in possum diet. This discussion will attempt to explore further reasons which may explain possum diet at Cass.

5.4.3 Foliage

Foliage preference in possum diet throughout New Zealand reflects the dominant vegetation type of the area in which the possum was studied. In pasture dominated areas, *Trifolium* species and introduced grasses tend to dominate possum diet (Gilmore, 1967; Harvie, 1973). However, this is not always the case, especially if native forest remnants are nearby, resulting in indigenous woody species sometimes forming the bulk of possum diet (Coleman, *et al.*, 1985), and also introduced woody species and herbaceous plants are regularly consumed (Coleman, *et al.*, 1985). In exotic pine forests, foliage of introduced broom (*Cytisus scoparius*), blackberry (*Rubus fruticosus*), herbs and grasses are the main species in possum diet. If indigenous woody species (e.g. *Fuchsia excorticata, Melicytus ramiflorus, Muehlenbeckia australis,* and *Aristotelia serrata*) are present in the exotic forest, possums will feed on these also. In native forests, possums will feed on a range of native woody species (e.g. *Weinmannia racemosa, Weinmannia silvicola, Metrosideros robusta, Metrosideros umbellata, Metrosideros excelsa, Beilschmiedia tawa, Dysoxylum spectabile, Podocarpus hallii,* and *Libocedrus bidwilli*). The consumption of different foods depends on which species are locally abundant.

A relatively small number of food groups dominated possum diet at Cass, which supports previous studies in New Zealand and Australia (Table 5.8) (Mason, 1958; Gilmore, 1967; Harvie, 1973; Fitzgerald, 1976; Warburton, 1978; Fitzgerald and Wardle, 1979; Fitzgerald, 1984; Coleman, *et al.*, 1985; Owen and Norton, 1995; Parkes and Thomson, 1995; Nugent, *et al.*, 1997; O'Cain, 1997; Rogers, 1997; Cochrane, *et al.*, 2003). Foliage was the dominant food group and consumption was relatively constant throughout the year, but fungi, bark, litter, fruit, seed, herb, and black mould were consumed in varying proportions throughout the year. The varied utilisation of these other food groups suggests that it is strongly influenced by seasonal changes in the availability, and possibly also the seasonal

palatability, of the key food types.

Table 5.8 Different possum diet studies (stomach analysis only) within New Zealand and Australia showing percentage of food groups within the diet. – represents food group not present in diet. t represents trace amount in diet.

	Foliage	Fruit	Flowers*	Seeds	Insects**	Birds	Fungi	Bark	Litter	Moss
Clout 1977 Mamahu Plateau, Central North Island	75.0	10.1	3.5	-	0.5	-	-	0.1	-	-
Warburton 1978 Ashley Forest, Canterbury	56.9	-	32.5	5.2	0.5	-	t	-	-	-
Stratham 1984 Tasmainan Forests, Australia	89.0	-	-	-	-	-	5.0	-	-	-
Owen and Norton, 1995 Hasst Valley South Westland	88.4	2.5	-	0.5	7.6	-	-	0.6	-	-
O'Cain 1997 Hoon Hay Valley, Banks Peninsula	29.8	65.2	-	0.5	0.3	0.2	-	-	-	-
Nugent *et al*, 1997 Hihitahi, Central North Island	77.6	22.06	1.3	-	-	-	0.6	-	-	0.63
Rogers 1997 Hihitahi, Central North Island	86.3	9.8	0.1	-	1.9	-	1.25	0.6	-	0.2
Cochrane *et al*, 2003. Springs Junction North Westland	78.4	0.4	11.1	t	0.1	-	0.0	2.1	-	t
de Zwart present study (unpub. MForSci Thesis) Cass, Arthurs Pass	72.7	5.5	0.7	4.7	t	t	8.4	5.9	6.2	0.3

* including Gymnosperm pollen cones

** including spiders

All food groups that were recorded here are relatively similar to those recorded in other studies in New Zealand (Table 5.8), excluding O'Cain (1997), who recorded only 29.8% of foliage in possum diet. The reason for this is probably related to the fruit species consumed being prolific fruiters, with the fruiting season mainly from November through to February, although ripe fruit was still available in late March and April (O'Cain, 1997). This suggests that throughout New Zealand possums tend to have a similar diet in terms of major food groups. Foliage is very important in possum survival, and all other food groups

appear to be seasonally important. Previous studies show that the bulk of possum diet comprises 50-95% of foliage (Nugent, *et al.*, 2000), which is consistent with this study (67% foliage). The other food groups comprise 33% of the diet, with individual groups contributing 9% or less of the possum diet. Therefore Hypothesis 4 is accepted, since there is a difference in utilisation of foliage and other food groups in possum diet in the study area over the study period.

5.4.4 Seasonal differences

The diet methods used in this study to quantify and compare the importance of seasonally available foods are subject to limitations due to differences in the physical properties of the individual seasonal foods. This can lead to underestimation of some food groups, such as flowers, and overestimated other food groups, for example fruit (Sweetapple and Nugent, 1998).

There was a statistically significant difference between diet in some seasons in this study. Therefore Hypothesis 3 is largely accepted. While the December sample was similar to those of March and June, the March and June diet were dissimilar from each other, and September was different to all other sample periods. These differences were driven by the variation of seasonally available food groups in particular seasons.

5.4.4.1 Bark, litter, herbs and fungi

Litter was consumed most in March and June, whereas in September and December the utilisation of bark and fruit dominated. This suggests that in March and June there is a decrease in palatable foods available, since litter is not very nutritious. Another reason for the high level of litter in the possum diet could be related to possums searching for food at ground level, such as invertebrates and fungi. Bark and litter have been found in minute quantities in previous possum diet studies in New Zealand (Clout, 1977; Owen and Norton, 1995; Cochrane, *et al.*, 2003). This present study found a relatively small proportion of bark in possum diet. This may be due to the small sample size.

Bark is available to possums throughout the year and was present in over 50% of possum stomachs in September. One suggestion of why possums consume bark is that they strip

off the bark to eat the soft cambial tissue (Fitzgerald, 1981). The cambial tissue is probably quickly digested, leaving little trace in the stomach. If this is true, then given the amount of bark in possum stomach, the amount of cambial tissue consumed is probably underestimated. In spring there is new tree growth and possibly increased nutritional value which may explain why bark was consumed in the highest proportions in spring. In this study, most bark was consumed at the end of winter/beginning of spring (September), which suggests that possums are struggling to find food. However, trees are starting to become physiologically active in September and there is almost certainly cambial activity and movement of food resources within the tree (D. Norton, pers.comm.).

Seeds were eaten in a relatively high proportion in March, but not at any other time of the year. This is most likely due to seasonal changes in plant reproductive activity, which means that seeds were abundant in March and not at any other time of the year. Warburton (1978) found similar levels of seeds in possum diet (5.2 % dry weight) and Owen and Norton (1995), O'Cain (1997), and Cochrane, *et al.* (2003) found small quantities in possum diet.

Herbaceous plants were consumed mainly in September and December, which suggests a season influence. The main herb that was consumed in this study was *Mycelis muralis* which, although it is not a dominant plant, it is widely scattered through the forest and shrubland at Cass. The high proportion of this herb in the possum diet may be due to the herbs being browsed as possums move between main food sources.

Fungi were present in possum diet in March, June, and December, making up the second highest annual dry weight in the possum diet. This suggests that fungi may be an important component in possum diet during these periods in the Cass study area. The lack of fungi in the September diet appears to be due to the higher use of bark and herbs, suggesting that either, bark and herbs are preferred, or fungi was not abundant in September. In Nugent, *et al.* (2000), an unpublished study found that fungi was one of the eight most dominant foods in the possum diet on Stewart Island in a podocarp-hardwood forest. Rogers (1997) found that fungi made up 1.3% of possum diet. No other published possum diet studies have found fungi to be a large part of the possum diet in New Zealand (Table 5.8). Stratham (1984) reported that that fungi made up 5.0 % of possum diet in two Tasmanian forests. In the Cass study area fungi made up a large part of possum diet, although fungi

were found in less than 40% of possum samples throughout the study period. The infrequent occurrences of fungi in possum stomachs suggests possums forage opportunistically on fungi.

5.4.4.2 Fruit, seeds, flowers

There was evidence of fruit and seed consumption in a minority of possum stomachs (except for *Aristotelia fruticosa* seed which was found in 62.5 % of possum samples in March), which suggests that these food items are not essential to possum survival. These fruiting and seeding plants are either present in small patches (*Aristotelia fruticosa*), or discretely scattered within the study area (*Ribes ova-crispa*, *Rubus squarrosus*, *Myrsine divaricata*, and *Acaena inermis*) (Chapter 3). *Ribes ova-crispa* was not found in this study area (Chapter 3) which indicates that the possum that consumed *Ribes ova-crispa* either foraged the fruit outside of the study area (in a garden in the Cass settlement, or this plant is found in a very secluded area of the study site, which was not seen in the vegetation data collection period). Fruit and seeds are heterogeneously scattered throughout the study site (Chapter 3), and are only available during particular seasons. Therefore, possums do not actively search for these energy-rich foods; rather they will consume these foods if they encounter them during their nocturnal feeding period (opportunistic feeding).

5.4.4.3 Food items

A total of 38 different food items were identified in the possum diet at Cass (Table 5.6), which when compared to other possum diet studies in New Zealand is relatively low. Gilmore (1967) found 64 different plant species in possum diet on Banks Peninsula (Canterbury). This area is a pasture-dominated site with possums relying on introduced grasses and clover. The large variety of food species found in the total possums diet on Banks Peninsula probably resulted from the variety of different vegetation types that were studied. Harvie (1973) conducted a study on farmland northwest of Waverley and found a total of 100 different food items. Warburton (1978) found 23 different food species in possum diet in an exotic forest (Ashley State Forest 40 km north of Christchurch). Owen and Norton (1995) found 33 different food items in a *Nothofagus menziesii* forest in South Westland. Fifty different food items were found in a possum diet study in the Hoon Hay Valley, Port Hills (Canterbury) by O'Cain (1997). Two studies were undertaken in a

podocarp-hardwood forest in Hihitahi, Central North Island by Rogers (1997) and Nugent, *et al.* (1997). Rogers (1997) found 39 food items (comparable to Owen and Norton, 1995), while Nugent, *et al.* (1997) found 102. The possum diet study in a north Westland mixed-beech (*Nothofagus*) forest by Cochrane *et al.*, (2003) found 49 different food types in the stomachs. All these studies show that possums consume a wide variety of food items. Unfortunately there is a limited number of published diet studies (using possum stomachs for analysis) in New Zealand to compare this study with other possum diet studies in a variety of vegetation types. From the above studies there is an indication that possums in pasture-dominated systems (Gilmore, 1967; Harvie, 1973; O'Cain, 1997) are inclined to have a higher number of different food items in their stomachs than those in exotic forest systems (Warburton, 1978). Research shows that possum diet in native forest systems (Owen and Norton, 1995; Nugent, *et al.*, 1997; Rogers, 1997; Cochrane, *et al.*, 2003) has a similar number of food species as that in the study area. Most of the earlier possum diet studies in New Zealand have used possum faeces to analyse their diet (Fitzgerald, 1976; Fitzgerald, 1978; Fitzgerald and Wardle, 1979; Coleman, *et al.*, 1985; Cowan and Moeed, 1987; Cowan, 1990b) and are therefore not directly comparable with this study.

Plant species that were a major feature in possum diet at Cass are *Aristotelia fruticosa*, *Blechnum penna-marina*, *Podocarpus nivalis*, *Mycelis muralis*, and *Nothofagus solandri*. These five species appeared in over 30% of possum stomachs with a dry weight of approximately 50% that were sampled throughout the year. Therefore Hypothesis 5 is accepted as five plant species dominated possum diet in the study area from March 2001 to December 2001.

Aristotelia fruticosa was present in over 60% of possum's stomachs throughout March, June, September and December. Parkes and Thomson (1995) undertook the only other published study that has found *Aristotelia fruticosa* comprising a large component of possum diet, although few other studies have been undertaken in areas where this species occurs. *Aristotelia serrata*, which is the lower altitude relative of *Aristotelia fruticosa*, has been frequently found to be a major component in possum diet. *Aristotelia serrata* has frequently been part of the eight most dominant species in possum diet (Leathwick *et al.*, 1983; Owen and Norton, 1995; Nugent, *et al.*, 1997; Rogers, 1997). Nugent, *et al.* (2000) mentions that three studies (in Silver beech forest, South Westland, and in a podocarp-hardwood forest in Pureora, Central North Island) found *Aristotelia serrata* in possum diet.

These studies indicate that *Aristotelia serrata*, and possibly *Aristotelia fruticosa*, are chosen over other foods in areas where *Aristotelia* species are present.

Podocarpus hallii has been identified as a key species in possum diet on Banks Peninsula (Nugent, *et al.*, 2000), Stewart Island (Nugent, *et al.*, 2000), and Waihaha, West Taupo (Nugent, *et al.*, 2000). Nugent *et al* (1997) found 19% of total diet was from *Podocarpus hallii* in a Podocarp-hardwood forest in Waihaha. *Podocarpus nivalis* is a higher altitudinal relative of the *Podocarpus hallii* and was a dominant feature in possum diet in the Cass study area, having an annual percentage dry weight of 7.2% (the fourth most dominant food item in possum diet) and occurring in 44.4% of possum samples. The presence of *Podocarpus nivalis* in possum diet peaked in September. This is earlier than when the presence of *Podocarpus hallii* in diet peaked which occurred in summer (Nugent, *et al.*, 1997; Rogers, 1997). More possums foraged on *Podocarpus nivalis* in the December sample but only 4.6% was consumed. Parkes and Thomson (1995) also found *Podocarpus nivalis* to be a dominant species in possum diet (22% of total diet) in an alpine shrubland, Rangitata, Central North Island.

In terms of *Nothofagus solandri* forest regeneration, *Leptospermum scoparium* is a known key nurse species in New Zealand (D. Norton pers. comm.). *Leptospermum scoparium* was not found in any of the possum samples at Cass, indicating that the main nurse species is not being negatively impacted on by possums. Therefore *Nothofagus solandri* regeneration is unlikely to be limited by possum browsing.

5.4.5 Birds and invertebrates

The role of birds and invertebrates in possum diet is evidence that possums are opportunistic feeders. Originally it was thought that possums consumed invertebrates accidentally (Harvie, 1973). It is now thought that possums consume invertebrates when the opportunity arises, rather than by accident (Cowan and Moeed, 1987), although small invertebrates that live inconspicuously on leaves or bark are probably eaten by chance. The invertebrates in this study were probably consumed by chance since they were found in trace amounts only.

The feather found in this diet was probably consumed by chance as this was only found

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once. Since no other bird remains were found in the possum stomach, the feather was possibly attached to some vegetation. Previous New Zealand possum diet studies that have found bird items in their diet include: Brown, *et al.* (1993), Parkes and Thomson, (1995) and O'Cain, (1997).

Animal tissues are high in nutrients and protein, so it would be expected that possums would consume more of these food items. The flesh of vertebrates and invertebrates is easy to digest compared to some plant material, which may be a reason why not more animal remains are found in possum diet. Because the possums at Cass had little animal tissue in their diet, it is assumed that they obtain most of their dietary requirements from sources other than animals. This differs from some studies in New Zealand which have had regular occurrences of animal foods in possum diet (Clout, 1977; Cowan and Moeed, 1987; Owen and Norton, 1995; Rickard, 1996; O'Cain, 1997).

5.4.6 Future threats on food types

Predictions about the change in plant composition due to browsing must be studied over many years before accurate conclusions can be reached about the actual effect of possum browsing on plant composition (Fitzgerald and Gibb, 2001). Previous studies have shown that possums have the potential to destroy individual plants (Kean and Pracy, 1953; Elder, 1965; Meads, 1976), leading to plant composition change. One diet plant composition change study found that possums in Orongorongo Valley, Wellington, browsed *Aristotelia serrata* and *Alectryon excelsus* from 1964 to 1967. Twenty-one years later these species were virtually eliminated from the area. Possums are thought to have been partially responsible for this through extensive browsing (Fitzgerald, 1976). *Podocarpus hallii* canopy cover decline has been thought to be caused by possum browsing in some areas of Westland (Pekelharing and Batcheler, 1990). These examples are of concern for Cass if possums have similar impacts on the higher altitude relatives of *Aristotelia serrata* and *Podocarpus hallii,* especially since *Aristotelia fruticosa* and *Podocarpus nivalis* are found in high proportions of possum diet at Cass. If possum density increases at Cass, the impacts of possums on *Aristotelia fruticosa* and *Podocarpus nivalis* may be more obvious, although these two species were not the dominant species in any of the vegetation communities. Long-term effects of diet alteration may change the structure and composition of different habitat types that possums occupy, but the extent of the changes

depends on the possum density.

Future threats to different possum food items will probably occur if possum density increases at Cass, especially to the main food items such as *Aristotelia fruticosa* and *Podocarpus nivalis*. Possum density may increase at Cass due to expanding forest and scrub communities (Chapter 3). Chapter 4 shows that possums den mainly in the forest and scrub areas. With the expansion of the forest and scrub communities there will be more den areas, as well as higher food availability (*Aristotelia fruticosa* and *Podocarpus nivalis* exist mainly in the scrub communities, Chapter 3). Currently, there is probably no immediate threat to the top four preferred species (excluding *Aristotelia fruticosa*) being over-exploited as they make up only 21.8% of the diet. *Aristotelia fruticosa* may become threatened in the future as it makes up an annual dry weight percentage of 26.7%. If possum density stays constant then the risks of plant composition change will also remain constant.

5.5 Summary

There was no statistically significant difference between female and male possum diet from March 2001 to December 2001. This result is similar to past possum diet studies in Australia and New Zealand. Female and male possums appear not to need different food items to survive.

Juvenile and adult possum diet also shows no statistically significant difference from March 2001 to December 2001. This result is also consistent with past studies in Australia and New Zealand that focused on possum diet. Competition may occur between juvenile and adult possums, but it appears that even though juvenile possums are less dominant, they still consume similar foods to the adults.

There was a statistically significant difference in possum diet between the different seasons from March 2001 to December 2001. These seasonal differences are the result of seasonally available food, such as fruit, seeds, flowers, fungi, and bark.

Foliage was consumed by possums more than all the other food groups together from March 2001 to December 2001. This is probably due to foliage being a more reliable (and

probably more palatable) food source than other food groups during the year. This result is consistent with past possum diet studies in Australia and New Zealand.

Five plant species dominated possum diet from March 2001 to December 2001. This result is similar to that of previous possum diet studies in Australia and New Zealand. These five species are probably the most preferred and available to the possum, meeting most of their nutritional requirements.

In terms of regeneration at the spatially heterogeneous environment at Cass, the plant communities will not be heavily impacted upon, since there is a low possum density. The browsing of a few main food resources may have other negative effects on other components of Cass's ecosystem; the consequences of which we have little understanding.

Leptospermum scoparium, a key nurse species for *Nothofagus solandri* regeneration, was not impacted on by possums. In terms of plant regeneration, possums are not likely to deflect the vegetation community succession towards *Nothofagus solandri*, which is important especially since *Nothofagus solandri* would have been the dominant tree species in the Cass area prior to deforestation.

For a better understanding of possum diet in relation to making accurate inferences on the possums' capacity to change plant composition in the Cass study area, a long term study is needed. However, destructive sampling and pest control has resulted in low densities of possums currently in the vicinity of the study area.

Chapter 6 Possum resource selection

6.1 Introduction

Johnson (1980) describes resource selection as the procedure by which the individual or social group chooses a resource. However, this view is simplistic as other factors, such as competition with the same species or another species, are involved in resource selection, which might make the resource unavailable. Therefore, resources used should be contrasted with resources available (or unused) before making conclusions regarding an individual's or social group's resource selection (Manly *et al.*, 1995). Selective use of a resource generally occurs when resources are found to be used disproportionately to their availability (Manly, *et al.*, 1995). The definition of resource usage is the quantity of the resource used by an individual or social group within a fixed period, and the availability of the resource is the amount that is obtainable by the individual or social group (Manly, *et al.*, 1995). Incorrect calculations of available and utilised resources can lead to flawed conclusions concerning resource selection (Rosenberg and McKelvey, 1999).

It is important to determine preference or avoidance of a given habitat type and food type in terms of their availability to each animal, as the results will enable development of successful conservation and management strategies. This will enable possum control in areas which possums preferentially prefer. Preference for a resource by an individual is the probability of that resource being selected if it is accessible on an equal basis with others (Johnson, 1980). Absolute statements of an organism's preference or avoidance of a resource should be guarded against since the resource may be fundamental to the organism's survival but only in small quantities, in which case to conclude that the resource is of little value to the organism would be incorrect (Johnson, 1980).

Non-random resource selection behaviour of an individual may be explained by the different scales of heterogeneity in the mammal's habitat. Determining the different scales of animal ecology to study is difficult, as the scales that the ecologist uses in measuring resource utilisation versus availability by organisms is probably very different to the scale by which the organism in question perceives its environment (Kotliar and Wiens, 1990). Also, animals might utilise and perceive different components of its habitat at different spatial scales, such as den sites and food resources (Orians and Wittenberger, 1991.).

To increase knowledge about individual interactions between animals and their environments, information is obtained about environmental structure at a scale appropriate to the organism of interest (Wiens and Milne, 1989). From this increased knowledge, inferences can be made at a broader scale (Wiens and Milne, 1989), thus enabling explanation of the mechanisms that may affect the population dynamics, metapopulation structure, and consumer-resource relationships (Turchin, 1991). The different spatial scales of habitat selection can be determined by recognising the hierarchical nature of selection (Johnson, 1980). First-order selection occurs at the physical or geographical range of the species of concern (Johnson, 1980). Determining the study area, which is the limit of availability, can result in spurious inferences as this assumes that all the resources within the study area are equally available to the organisms studied (Porter and Church, 1987). There may be some physical or geographical factor preventing the organisms from having access to the entire study area. The home range of the individual or social group is recognised as second-order selection (Johnson, 1980). Examination of selection at the second-order has limitations because it assumes that all resources within a delineated study area are available to all animals (Wilson *et al.*, 1998). Third-order selection determines the usage of various habitats within the home range (Johnson, 1980). Fourth-order selection can be referred to as the selection of food items in the various habitats within the home range (Johnson, 1980). Typically, few spatial scales are used in animal ecology studies (Cochrane, 1999; Chamberlain and Leopold, 2000; Ragg and Moller, 2000; Illera, 2001; Kazmaier *et al.*, 2001; McLellan and Hovey, 2001; Dunstone *et al.*, 2002).

Natural selection, ancestry, and experiences all determine an animal's behaviour relating to resource selection (Bell, 1991). These characteristics may be termed as constraints or filters within which an animal behaves in its environment. Factors that affect animal behaviour in relation to what choices a possum makes in selecting their resources for survival include behavioural, competition, and social interaction.

Generally possums do not have the choice to live in their ideal habitat (such as plenty of resources and no competition), because where they live is largely determined by the location of their natal area, especially for female possums (Day, *et al.*, 2000). Female offspring generally live most of their life close to their mother's habitat, whereas males will often travel long distances before they settle in one habitat (Cowan, 2000).

In New Zealand, possums have shown wide flexibility in the habitats that they occupy (Table 6.1). Most possum studies conducted in New Zealand focus on movements and/or diet, with one exception, Jolly (1976), who investigated possum habitat selection. Jolly (1976) mentioned that knowledge of possum movements and range use facilitates comprehension of their aptitude to adjust to their habitats. Jolly's (1976) research is the only published possum habitat selection study that has been conducted in New Zealand, and was done in a similar heterogeneous study area as this study. The main differences between this study the one conducted by Jolly (1976) is that Cass is situated at a higher altitude, and that the vegetation communities are different with the site from Jolly's (1976) study comprising pasture, orchard trees, other exotic trees, native forest, and mixed scrub.

Table 6.1 Possum studies that have been undertaken in a range of habitats in Australia and New Zealand by different authors.

Authors	Vegetation type	Authors	Vegetation type
Mason, 1958	Mixed podocarp-broadleaf forest	Gilmore, 1967	Mixed scrub pasture system
Crawley, 1973	Mixed podocarp-broadleaf forest	Jolly, 1976	Mixed scrub pasture system
Fitzgerald, 1976	Mixed podocarp-broadleaf forest	O'Cain, 1997	Mixed scrub-forest-grassland system
Ward, 1978	Mixed podocarp-broadleaf forest	Harvie, 1973	Farmland
Cowan and Moeed, 1987	Mixed podocarp-broadleaf forest	Jolly, 1973	Mixed scrub pasture system
Allen *et al.*, 1997	Mixed podocarp-broadleaf forest	Triggs, 1982	Pasture
Green and Coleman, 1980	Rata-kamahi forest	Thomas *et al.*, 1984	Pasture and poplar system
Batcheler, 1983	Rata-kamahi forest	Coleman *et al.*, 1985	Pasture-Alpine gradient, Westland
Clout and Gaze, 1984	*Nothofagus* forest	Green and Coleman, 1986b	Native forest and pasture system
Green and Coleman, 1986a	Mixed hardwood forest	Brockie *et al.*, 1987	Farmland
Cowan, 1990b	Podocarp/mixed hardwood forest	Paterson and Morris, 1995	Pasture
Pekelharing and Batcheler, 1990	Southern rata-kamahi	Brockie *et al.*, 1997	Farmland
Owen and Norton, 1995	*Nothofagus* forest	Cowan *et al.*, 1997 a	Farmland
Nugent *et al.*, 1997	Podocarp-hardwood forest	Clout, 1977	*Pinus radiata* exotic plantation
Sellar, 1998	Podocarp-hardwood forest	Warburton, 1977	Exotic forest
Efford *et al.*, 2000	Native forest remnant, Dunedin	Warburton, 1978	Exotic forest
Cochrane *et al.*, 2003	*Nothofagus fusca-N. menziesii*	Jacometti *et al.*, 1997	*Pinus radiata* exotic plantation

The overall objective of this chapter is to integrate the results from Chapter 3, Chapter 4, and Chapter 5, thus enabling a thorough investigation into possum resource selection at two different spatial scales. The first objective is to rank the different vegetation types by

their relative preference by possums in the study area. The second objective is to rank the most utilised vegetation type within a possum's home range (using all the radio-tracking locations, the den sites only, and the active periods only), and the third objective is to rank the utilisation of preferred vegetation species in possums diet in the study area.

Studying possum behaviour is important as knowledge of their behaviour will assist in possum management programmes, enabling the managers to effectively target areas that possums utilise the most.

The hypotheses of this chapter are:

1) Possums will use the vegetation communities non-randomly throughout the study site (second-order).
2) Possums will non-randomly use the vegetation communities within their individual home range (third-order).
3) Possums will prefer certain vegetation species in their diet within the study area (second-order).

6.2 Methods

The utilisation versus available resources that were calculated in this study conformed to Design 3 (Thomas and Taylor, 1990; Manly, *et al.*, 1995). With Design 3, individuals are identified and collected, and at least two of the sets (used resource units, unused resource units, available resource units) are sampled for each animal (Thomas and Taylor, 1990; Manly, *et al.*, 1995). Design 3 allows for resource selection for every individual animal, consequently estimates calculated from observations on individual animals may be utilised to estimate parameters for the population of animals and estimates of variability of these estimates (Manly, *et al.*, 1995). This design allows for the analysis of the utilised resources and the available resources for each possum.

Data that is used for this chapter come from Chapter 3, Chapter 4, and Chapter 5. During the radio-telemetry sampling period, possums were located in grid cells and within these grid cells, it was possible to determine which vegetation community they were in; this vegetation community data was used (discussed in Chapter 4: 4.2.2 Radio-telemetry). The vegetation composition plots are used from Chapter 3 to contrast between the different vegetation communities. These three chapters have looked at the different scales of

heterogeneity that will be studied to investigate the availability and utilisation of the different types of vegetation, the vegetation types which are present in possums' home ranges, and the types of food items that are available to possums in the Cass study area.

The area of the vegetation communities was calculated in ArcView™ geographical information system (GIS). Intersecting the possum movement results with the vegetation data displayed in ArcView™ GIS (using Geoprocessing Wizard) enable the areas of each vegetation community that occurred in each individual possum home range to be calculated. This was done by overlaying the possum movement theme and the vegetation community theme. These calculations were used to compare the possum resources utilised to the resources available. The possum diet results (Chapter 5: Table 5.6) were used to calculate the preference indices in possum diet. The vegetation composition data (Chapter 3) was also used in conjunction with the possum diet results, because these vegetation results had calculated the composition of each plant species in each vegetation community. Although, these calculated vegetation communities assume even distribution of each plant species within each community it occurs in, which is not the case because within these individual vegetation communities, the plants are non-randomly distributed at a smaller scale. The plant species present in the diet were able to be compared to those recorded in the plant composition results (Chapter 3) in each community, thus making it possible to compare the food items used with the food items available.

6.2.1 Second-order selection

6.2.1.1 Home range selection

Originally, seven different vegetation communities were identified: swamp, grassland, shrubland, scrub 1, scrub 2, native forest and exotic forest (Figure 3.3). The study area boundary was chosen to encapsulate all possum movements with an external 100 m buffer zone. The results in the Possum Movement Chapter (Figure 4.4, Figure 4.5, Figure 4.6, Figure 4.7, Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11, and Figure 4.12) indicated that the possums were not often in the exotic forest, grassland and shrubland, which provided frequent zero values in the radio-telemetry data for each possum, therefore these vegetation communities were combined. Also, the two scrub communities were combined, to reduce the number of zero values. Merging similar community types reduces the amount of error which may be caused from numerous zero values, as well as reducing the number of

habitats, which will yield more robust results in compositional analysis since this analysis is a parametric test (Aebischer *et al.*, 1993). Merging the community types will decrease the sensitivity of the interpretation of the statistical test. Second-order selection will define which part of the designated study area the possum actually uses, and ranks them from the most used to the least used.

All radio-telemetry data, which is female and male, and juvenile and adult possums, were combined as it was found in Chapter 4 (4.3.1 Home range and range length variation between sexes) that there was no statistically significant difference between their movements. Also, female and male diet were combined as there was no statistically significant difference (Chapter 5: 5.3.1).

6.2.1.2 Diet preferences

Diet preference was estimated by comparing the annual percentage species composition in possum diet to the percentage species composition of the vegetation in the study area, using forage preference indices (PI).

6.2.2 Third-order selection

Third-order selection determines which components of the individual home range the possum uses. This calculation takes into account only the annual home range of each possum, using the home range locations from Chapter 4 (Table 4.2).

Other third-order selection calculations tested included using the annual active possum locations only, and then the annual den site locations only. The active period of possum movements include all the radio-location data (Chapter 4) that were collected during the nocturnal sampling periods. The den site locations were collected from Chapter 4, which includes the daytime den sites only. This enabled determination of whether possums den in different areas to where they are active. Due to the low level of home range locations, separating them into the different sampled periods such as active movements, and den sites will decrease the level of accuracy in the test, thus resulting in either overestimating, or underestimating the actual possum home range utilisation versus availability. Although, the MCP home range estimates is a robust technique for calculating home range estimates, it

takes into account the low number of radio-location samples (discussed further in Chapter 4: 4.2.4).

6.2.3 Compositional analysis

Habitat selection was analysed using compositional analysis of log-ratios, which is a two-step process: 1) test for overall non-random use, and 2) test between each habitat type to find preferences (Aebischer, *et al.*, 1993). This is done by using log-ratio data, which makes the proportion data independent (Aitchison, 1986).

Compositional analysis statistically determines whether organisms use the habitat randomly or non-randomly, and then it ranks the different habitats from the most probable preferred habitat to the most probable least-preferred habitat (Aebischer, *et al.*, 1993). The resultant ordering of habitat types is subject to error, as the habitats may be insignificantly used more than others (Aebischer, *et al.*, 1993). This means that one habitat type may have been used slightly more than another habitat, which then gets a higher ranking, but overall, the habitats were used almost to the same extent (thus there was no statistically significant difference between the two habitats).The actual result of the ranking matrix may be assessed by the p-value (at $p < 0.05$) which gives a reliable indication on how much the different habitats vary (Aebischer, *et al.*, 1993).

The output of the compositional analysis is ranked in a simplified matrix based on the MCP home ranges estimates of the proportion of used habitat types versus the total proportion of available habitat types within the study area (Aebischer, *et al.*, 1993). Each element in the matrix was replaced with symbol: a triple sign represents significant deviation from random at $p < 0.05$ (Aebischer, *et al.*, 1993). If the communities have the same symbol then they are not statistically significantly different.

6.2.3.1 Missing habitat types

In theory situations all habitats are available to each animal, but in practice, habitat compositions data from radiotelemetry studies may result in some habitats not being used and other habitats being used in high proportions (Aebischer, *et al.*, 1993). Merging the habitats or excluding habitats that are missing in most animals home ranges (a particular

habitat is available to the animal but is not utilised) will reduce the number of null proportions from compositional analysis, but not necessarily exclude them (Aebischer, *et al.*, 1993). The corresponding proportion is positive in the composition of available habitat, but zero in that of utilised habitat, in which the zero suggests that the use of a habitat was so low that it was not detected, as a result this meaning should be kept in the analysis (Aebischer, *et al.*, 1993). By doing this, the number of zeros will be reduced from the data set. Using zeros for the numerator or denominator in the log-ratio transformation will produce an invalid result, therefore a small positive value, less than the smallest recorded nonzero proportion, should be substituted (Aebischer, *et al.*, 1993). Another approach is to remove the null proportions from the compositional analysis is to remove the animals that include the habitat which is rarely used. This will result in losing information about the animals, but this will make the calculation more robust, although by doing this will reduce the sensitivity of the compositional analyses (Aebischer, *et al.*, 1993).

The home range estimates calculated using MCPs, were used rather than results from the Kernel home range estimate, which were not all treated equally. For the data relating to all of the possums it was necessary to use different smoothing factors in the Kernel home range estimates due to the cell size in the grid (discussed in Chapter 4: 4.2.9 Associated errors with analysis techniques). Effects of scale and diet selection were tested using MANOVA. The computer program SAS used BYCOMP file (Ott and Hovey, 1997) for this analysis.

6.2.4 Forage preference indices

The forage preference indices (PI), using (Ivlev, 1961) electivity index, was used to determine possum diet at second-order selection. Numerous possum and other mammal diet studies in New Zealand have based their forage PI using this method (Cochrane, 1994; Owen and Norton, 1995; Nugent *et al.*, 1997; O'Cain, 1997; Rogers, 1997). Therefore, for the purpose of this study forage PI was used to compare the different PI for individual possums. This will enable comparisons to be made with other possum studies in New Zealand.

Forage PI ratings express the relationship between plant usage versus availability (Loehle and Rittenhouse, 1982), with the ratings based on the differences between the animals

relative use of a plant and the proportion of the plant species in the habitat (Owen and Norton, 1995).

Preference ratings for plant species occurring in possum diet were calculated using the electivity index of Ivlev (1961), as follows:

$$PI = \frac{\%\ species\ A\ present\ in\ diet - \%\ species\ A\ available\ in\ vegetation}{\%\ species\ A\ present\ in\ diet + \%\ species\ A\ available\ in\ vegetation}$$

The resulting value will be between -1 and +1. A value of negative one indicates that an animal selects against the species (never found in the diet but found in high proportions in the vegetation) and a value of positive one indicate that the animal selects for the species (always occurring in the diet but not found in the vegetation).

Preference indices were only calculated for foliage because of the complexities and difficulties in measuring the amount of fruit, fungi, and animal foods, in the study area at any one time. This is because these non-foliage food types vary seasonally.

6.3 Results

Figure 6.1 illustrates the recalculated merged communities at Cass. Table 6.2 shows the new aspect, slope, tiers, area, total species present, species richness, Berger-Parker DI, and Shannon DI for merged communities at Cass, that were predicted from Chapter 3 (Table 3.3). The swamp community is the smallest vegetation community (4.6 ha), followed by the forest community (21.8 ha), then the shrubland community (69.8 ha), and finally the scrub community being the largest vegetation community at Cass (99.1 ha). The scrub community has higher species richness than the other vegetation communities (Table 6.2). The scrub community also has fewer dominant plant species, as well as a higher diversity index, than the other vegetation communities (Table 6.2). In comparison to the earlier Table 3.3, the vegetation communities still have similar results for aspect, slope, number of tiers, area, total species present, species richness, Berger-Parker DI, and Shannon DI for each individual community.

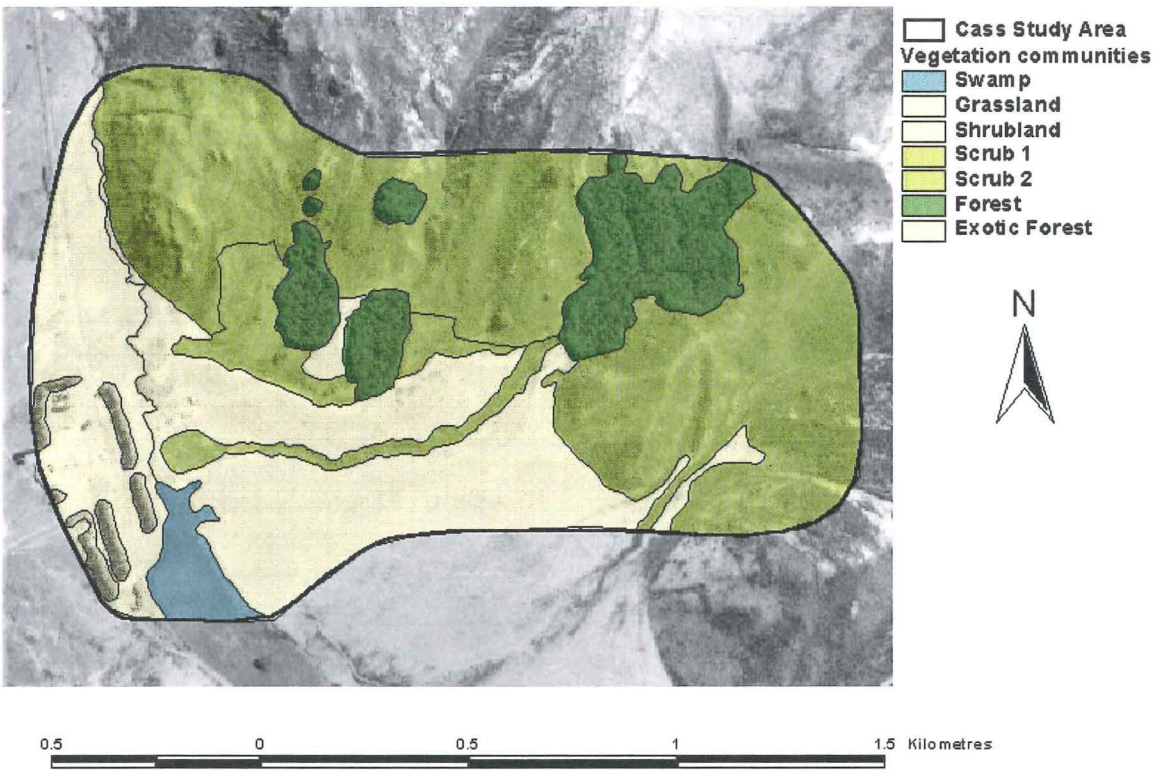

Figure 6.1 Combined vegetation communities that were used for possum resource selection in the Cass study area.

Table 6.2 Table showing aspect, slope, tiers, area, total species present, species richness, Berger-Parker DI, and Shannon DI results for the new combined communities in the Cass study area.

Variables	Swamp	Shrubland	Scrub	Forest
Aspect	229.0	250.4	213.0	181.4
Slope (°)	1.0	2.7±1.0	18.2±1.5	14.7±2.2
Tiers (1-4)	2	2	2	4
Area (ha)	4.6	69.8	99.1	21.8
Total species	1	56	68	33
Species richness	1	11.1±1.1	17.2±0.8	4.9±1.4
Berger-Parker DI (*d*)	1	0.1	0.1	0.203
Shannon DI (*H*)	0	11.4	14.6	11.0
Native species (%)	100	63	77	91

6.3.1 Habitat selection (second-order)

Seventy-two possum observations were used for possum resource selection at the second-order selection scale. There is a statistically significant difference between the level of use of vegetation types, showing that possums use the vegetation communities non-randomly (Wilks' Lambda is 0.010, Table 6.3).

There was a detectable difference of use between the shrubland, scrub, and the forest vegetation communities, and the swamp community (Table 6.4). The scrub communities were ranked as the most preferred vegetation community by possums in their home range (Table 6.4).

Table 6.3 Wilks' Lambda, *F*-value and *p*-value for second-order and third-order habitat selection using compositional analysis. **, signifies statistically significant at $p<0.01$, * signifies statistically significant at $p<0.001$.**

Selection level	Wilks' Lambda	*F*-value	*p*-value
Second-order	0.262	7.53	0.010**
Third-order	0.232	4.07	0.006***
- *Active period*	0.267	9.59	0.010**
- *Den sites*	0.078	29.37	0.002***

Table 6.4 Matrix output from compositional analysis based on possum home range comparing proportional habitat use with proportional composition habitat availability. Larger rank numbers represent greater preference. **, signifies statistically significant at $p<0.01$, * signifies statistically significant at $p<0.001$.**

	Swamp	Shrubland	Scrub	Forest	Rank
Swamp		---	---	---	0
Shrubland	+++		-	-	1
Scrub	+++	+		+	3
Forest	+++	+	-		2

6.3.2 Third-order selection

6.3.2.1 General habitat selection

Figure 6.2 shows the total percentage of time that all possums spent in the different vegetation types at Cass over the radio-tracking period. The scrub community is used the most frequently, followed by the forest and then the shrubland community.

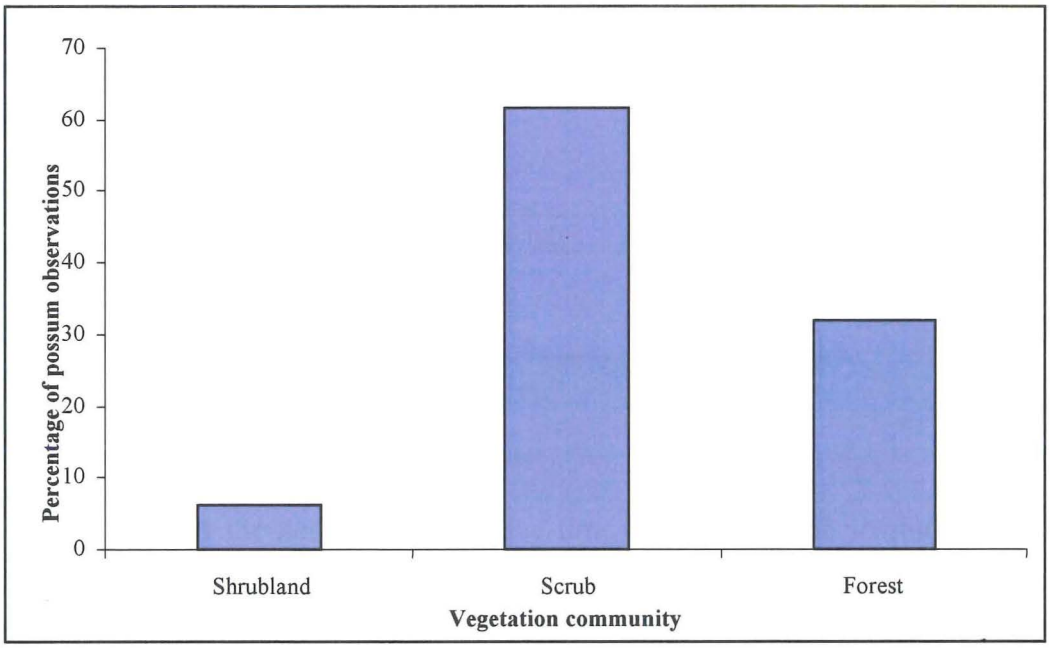

Figure 6.2 Percentage of total possum use (excluding Possum 2 and 38) in the three vegetation types.

Seventy-two possum observations were used for the active period of possum resource selection at third-order selection. The unpreferred habitat type (swamp) that was determined from the second-order selection comparison was eliminated from the third-order selection calculations, as the majority of possums were not found in the swamp, thus resulting in numerous null proportions. Loss of information and a potential bias may occur from eliminating these two possums, but it is assumed to be insignificant, and with the removal of null proportions made the analysis more robust (Aebischer, *et al.*, 1993).

There is an overall statistically significant difference between the composition of vegetation communities in the individual possum home ranges and their use of these communities; possums use the vegetation communities non-randomly within their home range (Wilks' Lambda is 0.006, Table 6.3).

The shrubland community was used significantly less than the scrub and forest communities (Table 6.5). The scrub and forest community are the most preferred habitat in the possum's home range (Table 6.5).

Table 6.5 Matrix output from compositional analysis based on possums movements comparing proportional habitat use with proportional composition habitat availability within their home range area. Larger rank numbers represent greater preference. **, signifies statistically significant at $p<0.01$, * signifies statistically significant at $p<0.001$.**

	Shrubland	Scrub	Forest	Rank
Shrubland		---	---	0
Scrub	+++		+	2
Forest	+++	-		1

6.3.2.2 Active area selection

Figure 6.3 illustrates the percentage of active time each individual possum spent in the different vegetation types at Cass over the radio-tracking period. The scrub community is utilised the most, followed by the forest and then the shrubland community.

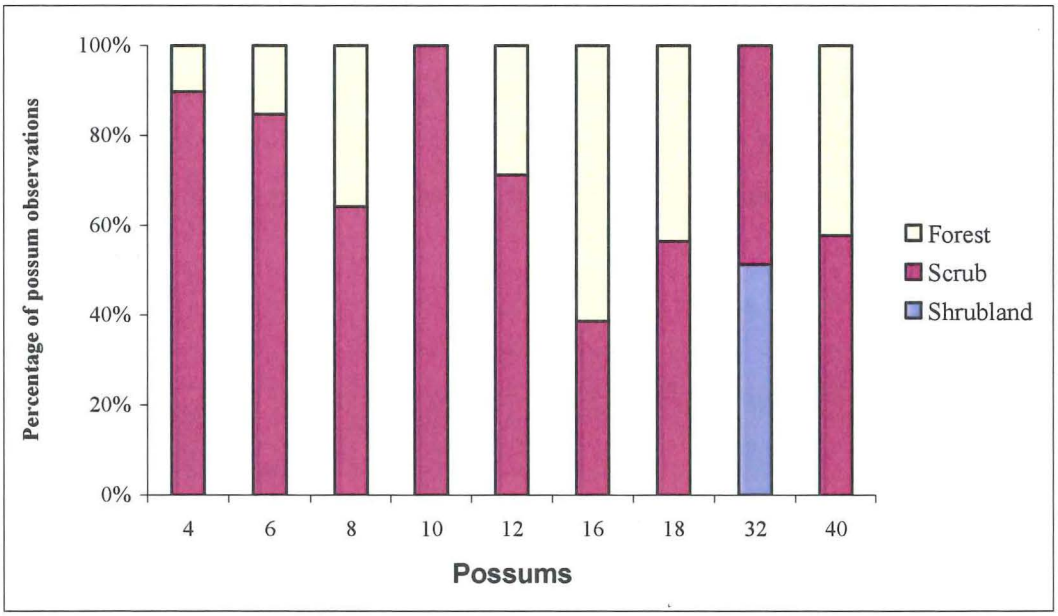

Figure 6.3 Percentage of all active periods of individual possum use (excluding Possum 2 and 38) in the three vegetation types.

Fifty-four possum observations were used for the active period of possum resource selection at third-order selection. Overall there was a statistically significant difference between the different vegetation communities used by possums whilst active, with Wilks' Lambda having a significant p-value (Table 6.3).

The scrub community was the most preferred by active possums (Table 6.6). The forest

community was ranked as the second preferred used vegetation community after the scrub community, although there is no statistically significant difference between the two communities. The shrubland was used significantly less that the scrub and forest communities (Table 6.6).

Table 6.6 Matrix output from compositional analysis based on active movements of possums comparing proportional habitat use with proportional composition habitat availability in their home range area. Larger rank numbers represent greater preference. **, signifies statistically significant at $p<0.01$, * signifies statistically significant at $p<0.001$.**

	Shrubland	Scrub	Forest	Rank
Shrubland		---	---	0
Scrub	+++		+	2
Forest	+++	-		1

6.3.2.3 Den area selection

Figure 6.4 illustrates the percentage of active time each individual possum spent in the different vegetation types at Cass over the radio-tracking period. The scrub community was used the most, followed by the forest. The shrubland community was not used for den sites.

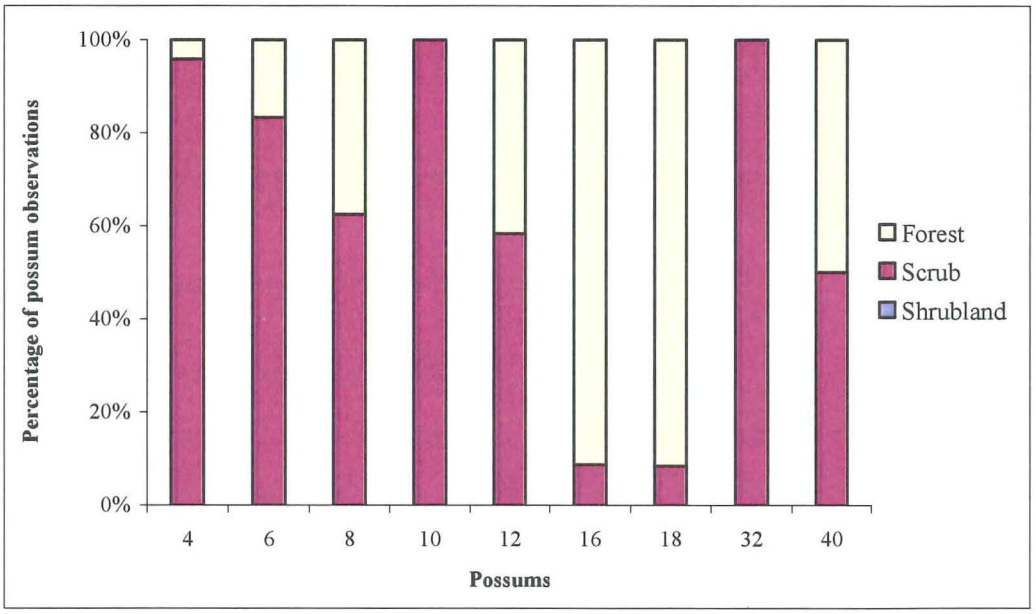

Figure 6.4 Percentage of all active periods of individual possum use (excluding Possum 2 and 38) in the three vegetation types.

Eighteen possum home range observatios were used for the denning period of possum resource selection at third-order selection. There was a statistically significant difference in possum den site usage of the vegetation communities in the study area, with the Wilks' Lambda test producing a significant *p*-value (Table 6.3). This means that possums were using the vegetation communities, in terms of suitable den sites, non-randomly. The den site calculations used fewer radio-telemetry samples from Chapter 4, than the active sample, since more active samples were collected. The smaller number of observations may reduce the power of compositional analysis, although using the MCP calculation for the home range size is a robust method for data that has low levels of data samples (discussed in Chapter 4: 4.2.4 Home range).

Of all three vegetation communities present, the forest community is ranked as the most preferred, followed by the scrub community, and the shrubland community (Table 6.7). The shrubland community was preferred statistically significantly less than the scrub and forest community (Table 6.7).

Table 6.7 Matrix output from compositional analysis based on possum den sites comparing proportional habitat use with proportional composition habitat availability in their home range area. Larger rank numbers represent greater preference. **, signifies statistically significant at $p<0.01$, * signifies statistically significant at $p<0.001$.**

	Shrubland	Scrub	Forest	Rank
Shrubland		---	---	0
Scrub	+++		-	1
Forest	+++	+		2

6.3.3 Diet preferences (second-order selection)

6.3.3.1 Overall seasonal preference indices

Preference index values for the seasonal foliage results are shown in Table 6.8. On an annual basis, *Mycelis muralis*, *Myrsine divaricata,* and *Aristotelia serrata*, have the highest preference scores. Overall, only *Mycelis muralis* was present in a high proportion of possum samples, and *Myrsine divaricata* and *Aristotelia serrata* were present in a small number of samples (Table 6.8). These plant species were the only food items that have positive preference values throughout the entire diet study, which is because they were not

found in the vegetation communities but were browsed on in relatively high proportions (Table 5.6).

Podocarpus nivalis, Aristotelia fruticosa, and *Muehlenbeckia axillaris* were the next most preferred species, although they produced annual negative preference indices, with *Podocarpus nivalis, Aristotelia fruticosa* present in a high proportion of possum samples (Table 6.8). These plants were browsed in relatively high proportions and the plant species were common in the study area.

Acaena inermis, Blechnum penna-marina, Rubus schmidelioides, Trifolium repens, Nothofagus solandri, Poa colensoi, Hypochoeris radicata, Coriaria sarmentosa, Coprosma species, Leptospermum scoparium, and *Ozothamnus leptophylla*, had negative preference values throughout the study period (Table 6.8). These plant species were only found in a few possum samples and they had a negative preference value since they were not common in the diet but were common in the study area.

Table 6.8 Preference ratings for plant species found in the total possum samples. n, number of possum samples the species was found in.

Diet species	Annual	n 49
Mycelis muralis	0.75	15
Myrsine divaricata	0.75	5
Aristotelia serrata	0.25	1
Podocarpus nivalis	-0.14	19
Aristotelia fruticosa	-0.27	40
Muehlenbeckia axillaris	-0.32	4
Acaena inermis	-0.43	10
Blechnum penna-marina	-0.43	11
Rubus schmidelioides	-0.43	6
Trifolium repens	-0.47	12
Nothofagus solandri	-0.57	17
Celmisia gracilenta	-0.70	1
Pittosporum divaricatum	-0.73	8
Poa colensoi	-0.87	2
Hypochoeris radicata	-0.95	1
Coriaria sarmentosa	-0.97	2
Coprosma species	-0.99	1
Leptospermum scoparium	-0.99	1
Ozothamnus leptophylla	-0.99	1

Figure 6.5 illustrates the foliage species that were present in the vegetation samples (Chapter 3, Appendix 1) and in the possum diet samples at Cass. It can be seen that the

scrub community has a higher abundance of the majority of the plants present in the possum diet, followed by the forest community, and then the shrubland community. *Aristotelia fruticosa, Blechnum penna-marina*, and *Podocarpus nivalis*, the dominant food items in possum diet (Table 5.6) had the highest abundance in the scrub or forest community (Figure 6.5).

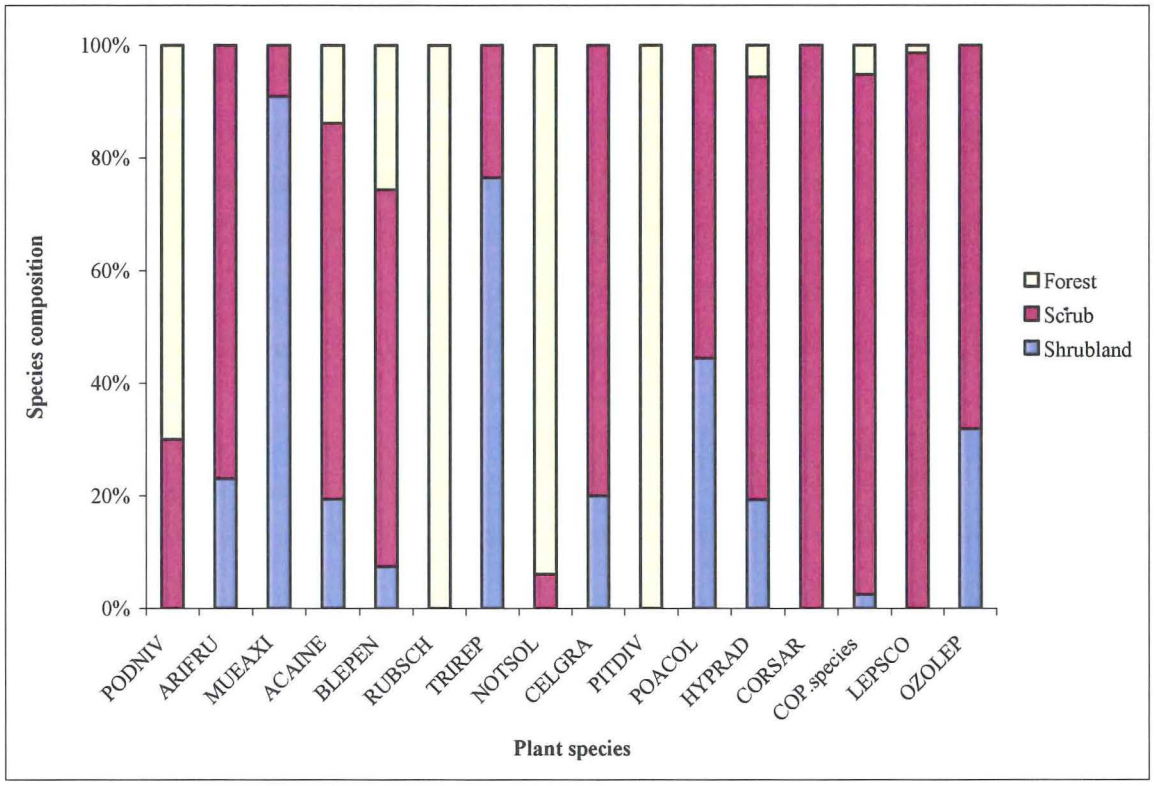

Figure 6.5 Species composition, from vegetation samples, in forest, scrub, and shrubland community of the plant species that were present in possum diet at Cass, excluding plant species that were not found in the vegetation samples. Species codes are the first three letters of the generic and specific names for each species (See Appendix 1 for full names).

6.4 Discussion

Intra-specific and inter-specific competition (briefly discussed in Chapter 4: 4.4) may determine what resources an animal utilises in order to survive. In New Zealand, possums have relatively few competitors, parasites, or predators, which are why possums have been successful in invading many different habitats (Clout and Ericksen, 2000).

The main competition for possums is other possums. In the study area the possum population in relatively low (Appendix 2). Possums most likely arrived in the Cass area by the late 1960s (Pracy, 1974) which may explain the current low density of possums. Other

reasons for low possum density may be attributed to intra-specific competition, such as competition for den sites, adequate food resources, and available mates. Den site competition may not be a major factor influencing low possum density since possums are known to share dens (Cowan, 1990a), even though den sharing generally occurs between mothers and daughters. Possums have been seen sharing dens ranging from very rarely (Paterson, *et al.*, 1995) to a daily likelihood probability of 0.07 (Caley *et al.*, 1998). The possum movement study (Chapter 4) did not result in possums sharing den sites, but this does not mean that it does not occur, especially as only 12 possums were radio-tracked, and the possum density was one possum per hectare (Appendix 2), within the home range areas of the radio-tracked possums (c. 110 ha). Although this is probably an overestimation of the possum population (discussed in Appendix 2). Therefore, it seems that the lack of den sites may not be a major factor in possum population size. Competition for food resources and habitats may be the limiting factors in possum population size.

6.4.1 Habitat selection by active possums

The scrub, forest and shrubland vegetation communities were utilised significantly more than the swamp vegetation community by possums during the active part of their night at second-order habitat selection. Also, the scrub and forest communities were utilised significantly more than the shrubland community, at third-order habitat selection. Therefore, Hypotheses 1 and 2 are accepted, since possums use the vegetation communities in the study area non-randomly (Hypothesis 1), and that possums use the vegetation communities present in the possums' individual home ranges non-randomly (Hypothesis 2). The scrub and forest communities most likely have more preferred resources, such as food resources (Figure 6.5) and den sites, thus influencing preference towards these communities over the shrubland and swamp communities. Possum movement studies in New Zealand have reported that possums den in a variety of scrub communities which suggests that possum den close to the ground (Gilmore, 1967; Harvie, 1973; Coleman *et al.*, 1985; O'Cain, 1997), whereas in Australia, possums normally use tree hollows, which they compete for with birds and reptiles (Green and Coleman, 1986). Possums in Australia were found to den only at ground level when trees are absent or scarce (Kerle 1984; Green and Coleman, 1986).

Most food items that were present in the possum diet at Cass (Chapter 5 and Table 5.6) are

present mainly in the scrub and forest vegetation communities (Figure 6.5), but some food species were found in the shrubland community (Figure 6.5 and Appendix 1). This indicates that food items in the scrub and forest community are influencing possum movement towards these areas.

Scrub communities throughout New Zealand are adequately dense to act as a defence mechanism from aerial predators (Cowan *et al.*, 2000), which may be a reason why possums at Cass are frequently in the scrub community. Moreporks (*Ninox novaeseelandiae*) and Australasian harriers (*Circus approximans*) have been reported to prey on young possums (Cowan, *et al.*, 2000). Another reason why possums use the scrub communities may be that possums do not have many ground predators in New Zealand therefore they do not need protection from them. The main predators of possums are humans, and feral cats (*Felis catus*), although stoats (*Mustela erminea*) and ferrets (*Mustela furo*) prey on young possums (Cowan, *et al.*, 2000).

The significant result for possums preferring the scrub and forest community does not necessarily mean that possums always prefer these vegetation types. Two possums spent a large proportion of their time in the swamp community (Figure 4.4, Figure 4.5, Figure 4.8, and Figure 4.9). The *Typha orientalis* grew densely in the swamp community, which created a dry environment for small animals to use as a habitat. The average possum weight at Cass was 2.9kg (Table 4.1), which appears to be light enough for possums to walk through the swamp community without crushing the plants and causing the possums to get wet. Other New Zealand studies that have reported possums utilising swamp communities are Cowan, *et al.* (1996), Brockie, *et al.* (1997), and Cowan, *et al.* (1997).

Possum preference for particular habitats in heterogeneous systems may have both positive and negative consequences for the regenerating vegetation systems at Cass. Fifty-four percent of radio-tracked possums exhibited bimodal ranging behaviour (Chapter 4: 4.3.4), which occurs when possums incorporate two different habitat types in their home ranges: the scrub, forest, and swamp vegetation communities in this study. In terms of conservation, the benefit of possums exhibiting bimodal behaviour is by possums consuming the fruit and seeds of native species and then the possums deposit their faeces in another habitat. This disperses the seeds to other areas, resulting in the likelihood of regeneration of these plant species in other areas (Lopez, 1998). The possum diet at Cass

showed that possums consume the fruit and seeds from the following native plants; *Aristotelia fruticosa, Rubus squarrosus, Myrsine divaricata*, and *Acaena inermis* (Table 5.6). One negative effect of possum bimodal behaviour is possums disperse exotic plant species into other areas, where they start regenerating. At Cass, possums consumed the fruit of *Ribes ova-crispa* (Table 5.6), which is an exotic plant in New Zealand. One problem with this theory is that it is not known if these seeds will remain viable following defecation. Lopez (1998) did preliminary tests on some plant seeds (*Sambucus nigra, Melicytus ramiflorus, Myoporum laetum, Muehlenbeckia complexa, Solanum aviculare*, and *Fuchsia excorticata*) in a laboratory and found that some of the seeds consumed in possum diet in her study remained viable. Further investigation is required for the different fruiting plant species that were consumed by possums at Cass.

The possums at Cass rarely used the grassland, which is a result that differs to most possum studies that include grassland vegetation, in New Zealand. Most studies that were close to grasslands, resulted in possums utilising this area, either for foraging, or for moving from one vegetation type to another (Gilmore, 1967; Harvie, 1973; Jolly, 1976; Coleman *et al.*, 1985; Green and Coleman, 1986; Brockie *et al.*, 1997). *Trifolium* species and introduced grasses were eaten in quantity and by a large proportion of possums throughout Gilmore's (1967) possum diet study. Thirty percent of possum diet on farmland northeast of Waverly (Harvie, 1973) comprised *Trifolium* species and introduced grasses, and 20% of pasture species comprised possum diet in a mixed hardwood-pasture system (Coleman *et al.*, 1985). Jolly (1976) and Brockie *et al.*, (1997) found that possums moved up to 1600 m across pasture, whereas Coleman and Green (1986) reported that possums moved up to 1200 m through forest that was adjacent to grassland, to feed. Reasons for why possums at Cass do not utilise the grassland community to a greater extent is unknown, but is most likely related to the scrub and forest communities having more food resources, thus the possums do not need to utilise the grassland resources. *Trifolium repens* was only eaten in small proportions of possum diet at Cass (1.5% annual dry weight), and found in a low proportion of possum stomachs (Table 5.6). Other grass species were very rarely consumed, and in only a small proportion of possum samples (Table 5.6). Possum 32 was the possum that utilised the grassland and shrubland communities the most (Figure 4.10, and Figure 4.11). Possums 2 and 32 may have cross the grassland to get from the forest remnant to the swamp, although Figure 4.5 and Figure 4.9 show that they mainly use the scrub gully as a corridor to get to either vegetation type.

An implication for efficient possum management relating to the knowledge of possum preferred habitats is important, as this will enable effective possum controlling in the areas where possums are more likely to be. Targeting habitat types that possums prefer will result in more possums being caught, rather than placing possum control mechanisms throughout all the habitat types, especially in areas where there are not likely to be any possums.

6.4.2 Habitat selection by denning possums

Within the study area possums statistically preferred to den in the scrub and forest vegetation communities than in the swamp and shrubland communities. In the forest community, possums are more likely to den in the trees, and in the scrub community the possums are more likely to den at ground level under shrubs (Chapter 4: 4.3.5). The vegetation in the scrub community grows densely, thus providing adequate den sites for possums, as well as being close to some food sources that were used in relatively high proportions, such as *Aristotelia fruticosa* and *Podocarpus nivalis* (Table 5.6, Figure 6.5, and Appendix 1).

Possum den sites in native forest systems include hollow logs, windthrow, clumps of epiphytes, flax, and vines (Day, *et al.*, 2000), or underground in large root systems of trees (pers. obs.). Generally, possums have been found to den in trees above the ground, rather than on the ground or under the ground (Day, *et al.*, 2000), although, compared to possums in Australia, New Zealand possums were more likely to den on the ground, or under the ground (Green and Coleman, 1986a).

The factors that influence possum den site choice, and the frequency that these den sites are used, may have important implications for possum management (Cowan, 1989). The first implication is that the amount of suitable den sites may be acting as a population density factor (Clout, 1977, Triggs, 1982), and secondly, den sites may be a common site for possums to transmit bovine tuberculosis to other possums (Cowan, 1989). Bovine tuberculosis may be transmitted to other possums at a faster rate if the possums share den sites. The possums studied at Cass did not share den sites with each other, so there is a small probability that this may happen at Cass. However, currently there is no known bovine tuberculosis in the Cass area, but the bovine tuberculosis vector risk area is very

close (Figure 20.1, in Coleman and Livingstone, 2000).

The conservation implications regarding possum control and possum den site preference is important, as knowledge of what habitats possums are more likely to den in will provide a basis of where to place possum control mechanisms. This will probably result in an efficient possum control strategy.

6.4.3 Foliage preference indices

The highly preferred food items of possum at Cass include *Mycelis muralis, Myrsine divaricata*, and *Aristotelia serrata,* although none of these plant species were found in the vegetation samples (Appendix 1). However, one *Aristotelia serrata* seedling was found by Burrows and Norton (1982) on the western shady side of Sugarloaf Bush. *Mycelis muralis* was found by Burrows and Norton (1982) on both the western and eastern sides of Sugarloaf Bush, which suggests that this plant will have similar distribution at the two other forest remnants. *Myrsine divaricata* was also found by Burrows and Norton (1982) on the western shady side of Sugarloaf Bush.

This result of this study suggests that the preference indices used for measuring possum preference for food items in their diet is very sensitive to plant species that were present in the diet, but not present in the vegetation. *Mycelis muralis* was the only highly preferred plant that was consumed by a large proportion of possums at Cass (up to 62.5%, Table 5.6). All other plant species that were consumed at Cass had negative preference indices. This result is caused by the preference indices used for this research being relatively insensitive to food items that were found in high proportions in possum diet, yet not very common in the vegetation. The results from the preference indices show that possums consume food non-randomly, with some species being highly preferred, therefore Hypothesis 3 is accepted.

Specific foliage preferences by possums in New Zealand are primarily influenced by the species composition in the area studied. For example, in a silver beech forest in South Westland, the four main food items in possum diet included *Aristotelia serrata, Muehlenbeckia australis*, insect larvae, and *Rubus* species (Owen and Norton, 1995), whereas in a podocarp-hardwood forest at Waihaha (Taupo) the four main food items were

Podocarpus hallii, Weinmannia racemosa, Myrsine salicina, and *Prumnopitys ferruginea* (Nugent, *et al.*, 1997). In an exotic forest at Ashley forest (Canterbury), *Cytisus scoparius, Pinus radiata*, grasses, and *Rubus fruticosa* were the four dominant food species (Warburton, 1978), and in pasturelands on Banks Peninsula, *Trifolium* species and grass species dominated possum diet (Gilmore, 1967). At Cass, the dominant food items in possum diet are *Aristotelia fruticosa*, fungi, *Blechnum penna-marina*, and *Podocarpus nivalis* (Chapter 5: Table 5.6), although these species did not have high preference values. *Mycelis muralis, Myrsine divaricata*, and *Aristotelia serrata* were not common in the study area, and did not make up a large proportion of all possum samples, but when present in the individual possum samples they were eaten in large proportions, suggesting these highly preferred species are sought after.

Preferences for food items may be related to psychological factors, such as how animals perceive, learn, remember, and, make choices (Shettleworth, *et al.*, 1993). Animals must first perceive the food item distinct from its background, and it must possess mechanisms for visual-motor dexterity to aim its strike accurately, then the animal had to discriminate the food item from the inedible or noxious but similar-appearing items and then the animal must be able to dispose of the food item effectively (Shettleworth, *et al.*, 1993). These are probably the main rationales for why possums in their current environment consume the variety of food items that possums consume throughout New Zealand. Another explanation for why possums consume certain food items is related to the behaviour of their mothers (Fitzgerald and Wardle, 1979). The food preferences of the mother are passed on to her offspring.

6.5 Management Implications

Possum browsing often has harmful and destructive effects on New Zealand native forests, although the effects of possums on native mixed vegetation communities, such as at Cass, are unknown. Possums in these heterogeneous ecosystems may improve the area in some respects, while they may deteriorate them in others.

Both positive and negative effects of possums on the environment may occur, through seed dispersal. This may increase forest and scrub regeneration (positive effects, O'Cain, 1997) or increase the risk of exotic plants spreading into native plant communities (negative

effect). These may be important issues to consider at Cass, which is a mosaic of regenerating vegetation communities. Possums at Cass consumed fruit and/or seeds from *Aristotelia fruticosa, Rubus squarrosus, Myrsine divaricata, Acaena inermis, Cytisus scoparius*, and *Ribes ova-crispa*, the first four species being native. These fruiting plants were present chiefly in the scrub communities. Consumption of these fruiting bodies may disperse seeds to other areas, thus facilitate vegetation community regeneration, or exotic species spreading into other vegetation communities. This dispersal may be further aided by the possums at Cass having relatively large home range sizes compared to other studies. Also possums moved through different communities, therefore the possums may have deposited faeces in areas other than the scrub and forest. Fruits and seeds from other plants may also have been eaten. Although there was no evidence of this in this study, this does not necessarily mean they were not consumed. Therefore a small probability exists that they were consumed. The last two possum diet samples (September and December) were numerically low, which possibly made these samples less reliable in terms of overall food items consumed during these times.

The negative effects of possums in the environment include browsing on new growth, competition with native fauna, predation on native fauna, and destruction of native plants, which in the long term may inhibit vegetation regeneration. The new plant growth, buds, and flowers are highly nutritious and high in energy, which is important for possum survival. However, the typical early successional plants to *Nothofagus* forest, such as *Leptospermum scoparium*, *Hebe* species, and *Dracophyllum* species, were not consumed by possums at Cass; therefore possums are probably not inhibiting forest regeneration at Cass.

Another negative effect is competition between possums and native fauna for resources such as dietary items. In other areas of New Zealand it is thought that possums are out-competing native fauna (chiefly birds) for resources, especially food items such as fruit. Possums have also been reported to compete with native fauna for nesting holes, as well as killing native birds and insects. Although at Cass, outwardly, it appears that there is no interspecific competition between possums and birds. Nevertheless, research is needed in this particular field to be certain.

Another environmental effect of possums includes foraging on plants to the extent that, in

the long term, the plant may be destroyed. This has been the case in native forests in New Zealand, but there is no obvious evidence of this at Cass. However there is the potential for this to happen in the future, especially if the forest community increases its canopy and sub-canopy vegetation diversity and size with more palatable plants such as *Aristotelia serrata* and *Griselinia littoralis* (seedlings found at Cass by Burrows and Norton, 1982). Also if the area of the forest increases, then the possum density at Cass is likely to increase. This may lead to possums killing individual plants that are palatable to them.

Possum home range preferences at Cass tended more towards the scrub and forest communities. The forest community was used more for denning and the scrub community was used for their nocturnal activities, such as foraging, although there was no statistically significant difference between possum use of these two areas. Because the possums preferred the scrub and forest communities, intra-specific and inter-specific competition most likely occurred in these two communities. In terms of inter-specific competition, possums might out-compete native fauna for resources. The swamp community was used by only two possums for denning and nocturnal activities, and the other grassland and shrubland communities were rarely used by any of the sample possums.

The patchy nature of the environment at Cass, and the common occurrence of bimodal behaviour offer opportunity for managing possum. An understanding of where den sites are located, for example, can help focus possum control operations around these areas as possums are more likely to encounter any control (such as traps) here (as they move to and from their den site). Also, knowledge of the areas where possums forage, for example, can enable possum control operations to be focused in these areas as possums are more likely to encounter any control, especially if the control techniques used are with bait. Because the bait stations are in areas where possums are foraging, possums are more likely to consume the bait when they are hungry.

In terms of management options for possums in high country areas similar to the Cass study area, it would be advisable to select the scrub community for placing control mechanisms, especially around the preferred dietary items. Although caution must be taken in placing control mechanisms by highly preferred species, as these preferences will vary from site to site. The next preferable area for placement of control mechanisms would be in the forest community (if there is a forest community in the area), if possible close to areas

where there appears to be high numbers of den sites. Controlling the other vegetation communities will probably not be very effective in terms of getting a high possum catch rate, since possums tend to be in these areas only for a short period, and do not generally feed in these areas.

6.6 Conclusions

Cass is a highly disturbed and rapidly regenerating heterogeneous landscape. A variety of past and present disturbances has dictated the current vegetation pattern, so the vegetation at Cass can be thought of as a dynamic mosaic responding to these disturbances. The vegetation communities in the area are in different stages of regeneration, with the grassland community in the earliest stages, followed by the shrubland, scrub 1, scrub 2, forest, and swamp communities, respectively. Possum impact on this type of vegetation mosaic has not been investigated in the past, thus providing the need for this research.

Compared to most possum-related studies, the Cass study area has a low possum density, which is probably related to possums being relatively new to the area (1960s), and also to the limited resources, such as dietary requirements and den sites, compared to fully forested environments.

Possum home range size at Cass is relatively large compared to possum home range size throughout New Zealand, with males and females having similar home range sizes. Possum bimodal ranging behaviour had a high incidence (54% of possums studied exhibited this behaviour) in this study. This is probably due to the heterogeneous landscape, given that these environments tend to have certain resources in some areas and other resources in other areas. Competition may also influence possum bimodal ranging behaviour. Some possums may have to den in areas further away from their food source due to more dominant possums occupying the den sites close to the food resource. Possum home ranges at Cass may also influence vegetation regeneration. The home ranges of possums are relatively large; as such possums may be distributing plant reproductive bodies to other areas, which may increase plant regeneration in these areas.

Possums exhibited no seasonal variation in their home range at Cass, which is not consistent with other studies that have been conducted in New Zealand. One possible

explanation for this could be that the seasonally available foods were present throughout the possum home range areas, with the result that the possums did not need to change their home range movements between the seasons towards these preferred areas. Another reason may be that males do not need to travel far to find mates.

This study has shown that the spatially heterogeneous nature of the vegetation at Cass influence possum habitat selection. Possums responded to the vegetation in a scale-dependent manner at Cass. Possums used the vegetation communities non-randomly at second-order and third-order selection. Also habitat use differed between the active period and den site selection period of possums. The preferred vegetation types of possums at Cass are the scrub and forest communities. Therefore, it can be concluded that possums spatially utilise resources in this study's heterogeneous environment.

Due to the lack of seasonal change in home range at the Cass study area, possum control does not have to be changed throughout the year, since the focused areas of possum movement does not statistically change with the seasons. An understanding of habitats which possums prefer to move around in, and where their den site areas are located, can help focus possum control operations around these areas.

Similar to other possum studies in New Zealand, possums fed mainly on foliage, although seasonally available foods such as fruit, seeds, flowers, and fungi, were consumed when they were present in the vegetation. The main food sources were *Aristotelia fruticosa*, fungi, *Blechnum penna-marina*, and *Podocarpus nivalis*. The browsing of these particular plants may have impacts on other components of the Cass environment and result in the loss of some individual species, the consequences of which we have little understanding. *Aristotelia fruticosa*, *Blechnum penna-marina*, and *Podocarpus nivalis* have not been found in many possum diet studies in New Zealand, although the lower altitude species *Aristotelia serrata, Podocarpus totara,* and *Podocarpus hallii* were relatively common in the low altitude possum diet studies. Although the food items consumed by possums in these studies is a result of what species are present in the location of these other possum diet studies. The canopy species (*Nothofagus solandri*) at Cass was not consumed in large proportions; therefore, possums will have little impact on the floristic structure and population structure of the forest.

Evidence of vertebrates and invertebrates in the possum samples was rarely seen, suggesting that these food items were consumed opportunistically, and that possums are not a threat to vertebrate and invertebrate populations.

The possible consequences at Cass, if the forest and scrub community increases is that the possum density in the area may increase, due to an increase in the occurrence of dens sites, and available preferred food items. Therefore possums will most likely have increased negative impacts on the environment. Therefore it is important to monitor the possum population at Cass, and if the population increases, controlling possums is advisable.

Based on the results of this research possum control measures are currently not essential at Cass, especially since possum density is low. However, due to this dynamic vegetation mosaic, possum control measures may be needed in the future. With the increasing area of regenerating scrub and forest communities there is the possibility that possum density will increase, as possum resources are likely to increase. This may result in a higher level of interspecific competition with native fauna. Therefore it is important to monitor possum density and its impact to ensure that Cass has minimal interference from possums.

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Appendix one: Vegetation species list, * indicates exotic plant

Species	Swamp	Grassland	Shrubland	Scrub 1	Scrub 2	Forest
Acaena inermis			+	+	+	+
Achillea millefolium *		+				
Aciphylla aurea		+		+	+	
Aciphylla subflabellata			+	+	+	+
Agrostis capillaris *		+	+	+	+	
Alepis flavida						+
Anthoxanthum odoratum *		+	+	+	+	
Aristotelia fruticosa			+	+	+	
Blechnum fluviatile						+
Blechnum penna-marina			+	+	+	+
Blechnum procerum						+
Brachyglottis bellidioides				+	+	
Carex breviculmis					+	
Carex goyenii		+		+		
Carmichaelia rivulata			+			
Cassinia leptophylla						
Celmisia gracilenta				+	+	
Celmisia spectabilis			+	+	+	
Centaurium erethraea *			+	+		
Cerastium glomeratum *		+	+			
Cerastium vulgare *			+			
Cirsium vulgare *		+	+			
Clematis forsteri				+	+	
Coprosma parviflora					+	
Coprosma ciliata				+		
Coprosma microcarpa						+
Coprosma petriei			+	+		
Coprosma propinqua		+	+	+	+	+
Coprosma rugosa						+
Coprosma rhamniodes						+
Coriaria sarmentosa				+	+	
Corokia cotoneaster			+	+	+	
Craspedia incana				+		
Cynosurus cristatus *				+		
Cytisus scoparius *		+				
Discaria toumatou		+	+	+	+	
Dracophyllum species				+	+	
Elymus solandri			+	+	+	
Epilobium atriplicifolium			+			
Festuca novae-zelandiae		+	+	+	+	
Gaultheria antipoda			+	+	+	
Gaultheria crassa				+	+	
Geranium sessiliflorum			+	+	+	
Gonocarpus incanus		+				
Grammitis billardierei						+
Hebe salicifolia						+
Hebe venustula			+	+	+	+
Helichrysum filicaule			+			

* indicates exotic plant

Appendix 1 continued:

Species	Swamp	Grassland	Shrubland	Scrub 1	Scrub 2	Forest
Hieracium pilosella *		+	+	+	+	
Holcus lanatus *		+		+		
Hypochoeris radicata *		+	+	+	+	+
Hypolepis millefolium						+
Juncus effusus *		+		+		
Lagurus ovatus *		+		+		
Leptospermum scoparium			+	+	+	+
Leucopogon colensoi			+	+	+	+
Leucopogon fraseri			+		+	
Linum catharticum *			+	+	+	
Lotus pedunculatus *		+	+			
Luzula rufa			+	+	+	+
Lycopodium fastigiatum				+		
Muehlenbeckia axillaris			+	+		
Muehlenbeckia complexa				+		
Nertera ciliata			+			
Nothofagus solandri				+		+
Olearia avicenniifolia					+	
Ozothamnus leptophylla			+	+	+	
Phormium tenax		+	+	+		
Pimelia oreophila			+	+	+	
Pimelia prostrata				+	+	
Pimelia traversii				+	+	
Pinus radiata *		+				
Pittosporum divaricatum				+		+
Poa cita			+	+	+	
Poa colensoi		+	+	+	+	
Podocarpus nivalis				+	+	+
Polystichum richardii						+
Polystichum vestitum						+
Prasophyllum colensoi					+	
Prunella vulgaris *				+		
Pteridium esculentum			+	+		+
Ranunculus enysii				+	+	+
Raoulia subsericia			+	+	+	
Rosa rubiginosa *		+	+	+		+
Rubus cissoides						+
Rubus squarrosus						+
Rubus schmidelioides				+		+
Rumex acetosella *		+	+	+	+	
Schoenus pauciflorus		+	+	+		
Senecio wairauensis						+
Taraxacum officinale *			+	+	+	
Trifolium pratense *		+		+		
Trifolium repens *		+	+	+		
Typha orientalis	+					
Unicinia clavata						
Unicinia uncinata						+
Urtica incisa						
Viola cunningham			+	+		
Wahlenbergia albomarginata			+	+		

Appendix two: Possum density estimate

Introduction

Population density is an important factor to consider when determining possum movements, diet, and resource selection. The density acts as an indicator of the effects of possums on the biota and other aesthetic values (Efford, 2000). The amount of foliage consumed, the number of den sites used, home range size, and disease transmission, are important factors to consider when determining and managing a system. Therefore possum density is an important consideration in estimating impacts of the above factors, for management.

Methods

Possum density sampling was done by randomly locating Timms traps in a stratified area (shrubland, scrub, and forest communities). Vegetation community stratification was used as possum populations are not often regularly disseminated (Warburton, 2000). The possum populations are estimated from using the possums sampled in the radio-telemetry study (Chapter 4) and diet study (Chapter 5).

To calculate possum density Index-Manipulation-Index (Caughley, 1977, pg. 47) was used. This index bases its' population density estimates from a linear index of density calculated before and after a known number of animals are removed from the population. This study used the animals removed from the diet study that was conducted in 2001 (Chapter 5) and the area used was the average home range area possums used in 2000 (Chapter 4). The operational trapping area was calculated using minimum convex polygons (MCP's) which include the identified locations of an individual, thus estimating home range of an individual (Cowan and Clout, 2000). This analysis may be used when animals are added to the population, but these animals are given a positive number (+*C*), whereas removed animals are given a negative number (-*C*). Population size before treatment is given by:

$$N_1 = \frac{I_1 C}{I_2 - I_1}$$

Where N_1 is initial population size, N_2 is the post-population size, I_1 is the index of density before removal, C is number of individuals removed, and I_2 is the index of density after removal (Caughley, 1977, p.g. 47).

The assumption for this Index-Manipulation-Index method is that the population is closed during the removal period of individuals (Caughley, 1977, pg. 48). To minimize the bias realistically, the whole experimental period should be done in as short a time as possible. In this study three months separate the possum removal periods (June to September, and September to December), thus increasing the chances of possums dying naturally in this experiment or dispersing into the area. Unfortunately this cannot be helped as possum population numbers were very low at the end the whole study, thus increasing other biases due to very few possums being caught (as can be seen in the September and December diet studies where few possums could to be caught) (Chapter 5; Table 5.1).

Using the Cass study area boundary as the total area used in the Index-Manipulation-Index method, may introduce a bias such as an overestimation of density because of boundary or edge effects (Otis *et al.*, 1978). Some animals that are caught may have a home range that extends out from the study area.

Results

Thirteen possums were caught over 26 trap nights in June, 2001. In September, nine possums were caught over 75 trap nights and in December 8 possums caught over 105 trap nights. From this, it was statistically calculated that 17 possums were to be at Cass after June possum trapping and 27 possums after the September trapping. These results are slightly ambiguous. In an attempt to overcome this bias, June and September results were averaged; therefore the result is 22 possums. To this, the 16 possums caught in March for the diet study were added to the calculated 22 possums, resulting in 38 possums. Therefore the estimated possum density at Cass is one possum per hectare (using possum Kernel home range total area of all the radio-tracked possums, which is 110 ha). Possums were difficult to catch in the last two months because possum numbers were depleted in the areas where the Timms traps were placed in areas (Figure 5.2) that were consistent with the possum movement study (Chapter 4, Figure 4.3).

Discussion

Possums are non-randomly distributed throughout the landscape for a variety of reasons such as heterogeneity and the abundance of resources within the landscape (Efford, 2000). If there is a high abundance of resources in one area then it would be expected to carry a higher possum density than in an area where resources are scarce, thus possums have a clumped distribution in the study area.

The population density in the Cass study area is relatively low compared to other possum density estimates throughout New Zealand (Table 1). It is difficult to determine why the possum population is low, but the low density may be the result of two factors: inadequate den sites and food resources. Possums were found to den in either the dense scrub or in holes in trees close to the canopy layer. With the regeneration of more scrub and forest communities there is likely to be an increase of den sites, possibly resulting in an increase in possum density. It would be useful to have information regarding possum densities in neighbouring areas; this would help explain whether the Cass population density is normal for the region.

Another reason for low possum density may be related to limited food resources. Most food items that were found in possum diet came from the scrub communities. With increasing regeneration of the scrub and forest communities, food resources are likely to increase. This may result in a higher possum density in the future.

In New Zealand high possum populations generally occur in habitats close to pasture. Podocarp-broadleaf forests carry higher possum densities (3.0-25.0 possums per hectare, Table 1), whereas beech forests (<0.5-1.7 possums per hectare, Table 1) and pine plantations (0.7-3.0 possums per hectare, Table 1) carry lower possum densities.

All the possums that were used in this study were all in good condition, which is a good indicator that possums are not over-populated.

Table 1 Possum population densities from intensive studies in undisturbed populations, based on Appendix 5.1 from Efford (2000).

Reference	Density	Years	Near pasture	Site
Triggs 1982	4.9	1981-82	Y	Mixed podocarp-broadleaf forest
Ramsey et al 1997 *	11.6	1996-98	Y	Mixed broadleaf forest
Ramsey et al 1997 *	3.6	1995-98	Y	Mixed podocarp-broadleaf forest
Ramsey et al 1997 *	3.6	1995-98	N	Mixed podocarp-broadleaf forest
Ramsey et al 1997 *	7.8	1995-98	Y	Mixed podocarp-broadleaf forest
Crawley 1973, Efford 1991 *, 1998	9.1	1967-97	N	Mixed podocarp-broadleaf forest
Ramsey et al 1997 *	10.5	1995-98	N	Mixed podocarp-broadleaf forest
Ramsey et al 1997 *	3.8	1995-98	N	Mixed podocarp-broadleaf forest
Ramsey et al 1997 *	8.9	1995-98	N	Mixed podocarp-broadleaf forest
Coleman et al. 1980	25.4	1978	Y	Lowland cut-over forest, *Weinmannia racemosa*, tree fern, emergent *Metrosideros umbellata*, podocarps
Coleman et al. 1980	10.8	1978	N	Mixed *Metrosideros umbellata/Weinmannia racemosa* and *Libocedrus bidwillii* forests
Efford et al 1999 *	6	1978	N	Mixed podocarp-hardwood forest (*Quintinia acutifolia, Weinmannia racemosa, Podocarpus hallii, Psuedowintera colorata* and *Libocedrus bidwilli*)
Coleman et al. 1980	19.8	1993-94	Y	Mixed-podocarp broadleaf forest
Coleman and Green, 1984	3.8	1980	N	Coastal mixed podocarp-broardleaf forest (*Dacrydium cupressinum, Prumnopitys ferruginea, Metrosideros umbellata, Weinmannia racemosa, Griselinia littoralis* and *Fuchsia excorticata*)
Clout and Gaze 1984	0.5	Jun-81	N	Nothofagus forest
Triggs 1982	2.7	1981-82	Y	*Pinus radiata* plantation
Clout 1977; Clout and Efford 1984	3	December 1974	N	*Pinus radiata* plantation
Warburton 1977	0.9	1975-76	N	*Pinus radiata* plantation
Triggs 1982	4.6	1981-82	Y	Tall scrub, mixed native and exotic
Olds 1982 *	4.4	1985-86	N	*Metrosideros excelsa-Metrosideros robusta* forest on lava flows
Brockie et al, 1997	8.8	April 1988	Y	*Salix* species, *Rubus fruticosus, Cortaderia spp., Phormium tenax*
Brockie et al, 1997	16.7	April 1988	Y	*Salix* species.
Brockie et al, 1997	0.2	1982-88	Y	Open mixed farmland, barns, tree rows, *Cortaderia*
Pfeiffer 1994 *; Paterson et al, 1995	7.2	1991-94	Y	*Leptospermum* scrub, *Ulex* and remnant broadleaf forest interspersed with pasture
Jolly 1976	1.2	1972-74	Y	Mixed farmland and scrub

* indicates unpublished references

Appendix three: Possum diet results

Frequency of occurrence (FO) results for monthly and annual possum diet in the Cass study area.

	Mar-01		Jun-01		Sep-01		Dec-01		Total	
FOOD TYPE	FO	%N	FO	%N	FO	%N	FO	%N	FO	%N
Aristotelia fruticosa	44.38	87.5	39.40	83.3	24.00	66.7	17.75	62.5	31.38	75.0
FUNGI	2.00	25	6.09	33.3	0.00	-	3.75	37.5	2.96	24.0
Blechnum penna-marina	2.63	25	1.21	16.7	0.00	-	30.58	50.0	8.61	22.9
Podocarpus nivalis	1.88	12.5	2.18	33.3	15.50	44.4	4.83	87.5	6.10	44.4
BARK	1.00	12.5	0.00	-	8.26	55.6	0.00	-	2.31	17.0
LITTER	6.31	37.5	8.90	88.9	2.17	55.6	0.00	50.0	4.34	58.0
EXOTIC GRASS	0.50	12.5	2.35	61.1	10.67	77.8	1.85	75.0	3.84	56.6
Mycelis muralis	1.50	25	3.50	33.3	0.00	-	14.00	62.5	4.75	30.2
Aristotelia fruticosa (seed)	12.13	62.5	4.65	11.1	0.00	-	0.00	-	4.19	18.4
Rubus schmidelioides	14.25	12.5	0.05	11.1	0.00	-	5.92	25.0	5.05	12.2
Nothofagus solandri	0.19	6.25	2.06	55.6	7.08	44.4	1.08	25.0	2.60	32.8
HERB	0.00	-	3.13	33.3	5.50	33.3	4.58	12.5	3.30	19.8
Pittosporum divaricatum	5.06	43.8	0.10	5.6	0.00	-	0.00	-	1.29	12.3
Muelenbeckia axillaris	0.00	-	5.86	16.7	2.25	11.1	0.00	-	2.03	6.9
Ribes ova-crispa (fruit)	0.00	-	0.00	-	0.00	-	1.92	12.5	0.48	3.1
Trifolium repens	0.38	12.5	1.46	22.2	0.01	11.1	4.42	62.5	1.56	27.1
PETIOLES	1.88	18.8	1.35	5.6	0.01	11.1	6.33	12.5	2.39	12.0
BLACK MOULD	0.00	-	4.39	11.1	0.00	-	0.00	-	1.10	2.8
Aristotelia serrata	0.00	-	3.60	5.6	0.00	-	0.00	-	0.90	1.4
Rubus squarrosus (fruit)	0.38	6.3	0.00	-	0.00	-	0.00	-	0.09	1.6
Celmisia gracilenta	0.00	-	0.00	-	0.33	11.1	0.00	-	0.08	2.8
Myrsine divaricata	1.75	12.5	1.18	11.1	0.00	-	0.50	12.5	0.86	9.0
Myrsine divaricata (seed)	0.00	-	0.21	11.1	0.00	-	0.00	-	0.05	2.8
Cytisus scoparius (flower)	0.00	-	0.00	-	0.00	-	0.00	87.5	0.00	21.9
Acaena inermis	3.06	18.8	0.70	16.7	3.92	33.3	0.08	12.5	1.94	20.3
Coprosma species	0.00	-	0.05	5.6	3.00	11.1	0.00	-	0.76	4.2
Ozothamnus leptophylla	0.00	-	2.75	5.6	0.67	11.1	0.00	-	0.85	4.2
Hypochoeris radicata	0.00	-	1.85	5.6	0.00	-	0.75	12.5	0.65	4.5
Leptospermum scoparium	0.00	-	0.00	-	1.00	11.1	0.00	-	0.25	2.8
Poa colensoi	0.00	-	0.66	11.1	0.00	-	0.00	-	0.17	2.8
Coriaria sarmentosa	0.06	6.3	0.06	5.6	0.00	-	0.00	-	0.03	3.0
MOSS	0.00	-	1.11	16.7	0.08	11.1	0.00	-	0.30	6.9
Acaena inermis (seeds)	0.56	18.8	0.00	-	0.00	-	0.00	-	0.14	4.7
Cyathodes colensoi	0.00	-	0.00	-	15.58	22.2	0.00	-	3.90	5.6
Pimelia fraseri	0.06	6.3	1.10	11.1	0.00	-	0.00	-	0.29	4.3
Viola cunningham	0.00	-	0.05	5.6	0.00	-	0.00	-	0.01	1.4
FEATHER	0.06	6.3	0.00	-	0.00	-	0.00	-	0.02	1.6
INSECT	0.00	-	0.00	-	0.00	-	0.25	12.5	0.06	3.1